Carex limosa L. (mud sedge): A Technical Conservation Assessment

Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project

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Cover Photo Credit

Carex limosa (mud sedge). Cover photograph by David Cooper; inset photograph: © 2003 Steve Matson, used with permission.

Summary of Key Components for Conservation of *Carex limosa*

Status

Carex limosa (mud sedge) is widely distributed throughout the northern hemisphere and is considered secure globally (G5). In USDA Forest Service (USFS) Region 2, this obligate wetland species occurs primarily in subalpine fens formed in small basins in the mountains of Wyoming and Colorado. A limited number of occurrences are also documented from the Nebraska Sandhills region. The fens supporting known occurrences of this species are primarily located on public lands managed by either the National Park Service or the USFS. Most occurrences appear to be generally secure from direct impacts, but many may be potentially vulnerable to indirect and cumulative impacts from land uses that alter their hydrologic or sediment dynamics. Because of the small number of occurrences known from the region (<100), Colorado and Wyoming natural heritage programs both rank *C. limosa* imperiled in the state (S2), and Nebraska Natural Heritage Program ranks it critically imperiled (S1) (NatureServe 2004). *Carex limosa* is not included on the Regional Forester's sensitive species list in USFS Region 2 (USDA Forest Service 2003), nor is it on similar lists maintained by other USFS Regions or the Bureau of Land Management.

Primary Threats

As a fen obligate in the region, the fate of *Carex limosa* is intimately intertwined with that of the wetlands in which it occurs. Historically, many fens have been altered hydrologically, typically through construction of ditches or other engineering structures. Peat mining has also directly impacted a limited number of fens. Both activities are currently uncommon on public lands and appear unlikely to represent a significant threat to most extant *C. limosa* occurrences. However, many of the fens historically impacted by humans continue to exhibit impaired function, and they often require active hydrologic restoration before any ecological recovery can begin. An additional historical impact of unknown extent is the construction of reservoirs, which could have affected fens through flooding. Since *C. limosa* is typically associated with small ponds or lakes, which are attractive sites for impounding and storing water, past and future water resource developments may have impacted the species.

Although direct impacts currently appear to be of little consequence to most Region 2 *Carex limosa* occurrences, impacts from a wide variety of activities are known to indirectly impact wetland structure and function, with potential implications for the species. Since fens are supported primarily by groundwater inflows, any activity that significantly alters the water or sediment yield from surrounding watersheds, such as logging or road construction, can deleteriously affect wetland vegetation. Climate change also has the potential to negatively impact fens by altering their hydrologic balance, and increasing decomposition rates enough to shift the system from one which accumulates peat to one that gradually loses it. Because *C. limosa* is typically found on floating peat mats that are able to rise and fall with fluctuating basin water levels, it may be relatively resistant to small changes in water levels resulting from climate change or altered water and sediment inflows due to changes in basin vegetation cover.

The large gradients in pH, nutrient, and cation concentrations within and among peatlands have generally been shown to strongly shape vegetation patterns, so any activities significantly altering water chemistry can be expected to impact fen ecosystems. However, *Carex limosa* naturally occurs across a wide range of pH and nutrient conditions, and therefore, it would not appear particularly sensitive to changes in water chemistry, as might occur, for example, with increased atmospheric deposition of pollutants.

Overall, we found no quantifiable evidence to suggest that the persistence of *Carex limosa* within Region 2 is presently threatened. Data from the relatively small proportion of sites that have received study suggest that occurrences are stable. However, since few sites supporting *C. limosa* have been studied in detail, evaluating trends for other occurrences in the region is impossible.

Primary Conservation Elements, Management Implications and Considerations

The general principle that conserving individual species is best accomplished through conserving its habitat applies to *Carex limosa*. Like a significant number of wetland and alpine species in the region, *C. limosa* was likely more widespread historically than it is at present (Weber 2003). Expansion of the species in the region, at least under current and predicted climate scenarios, appears highly unlikely due to limited habitat and potentially low dispersal distances. Consequently, management goals need to include explicit protections for fens since these unique ecosystems provide critical habitat for a range of rare species such as *C. limosa*, *C. livida* (Wahlenb.) Willd., *C. lasiocarpa* Ehrh., *C. diandra* Schrank, *Eriophorum gracile* W.D.J. Koch, *Drosera anglica* Huds., and *D. rotundifolia* L.

To improve management of *Carex limosa*, additional research is needed on a range of topics. Broad-scale peatland inventories are needed to better understand the abundance, distribution, and functional diversity of peatlands in the region. These kinds of studies also provide a useful framework for more fine-scaled investigations of fen hydrology, vegetation, and geochemistry, which represent the primary variables driving fen structure and function. In preparing this assessment, it has also become clear that more studies of *C. limosa* demographics and extensive population monitoring are needed in order to improve our understanding of the species and potential threats.

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INTRODUCTION

To understand and mitigate for potential environmental impacts from management activities and projects on individual species, the USDA Forest Service (USFS) requires basic information about species' biology, ecology, and conservation status. Unfortunately, such information for many species is sparse and scattered among a variety of disparate sources, largely unavailable to managers and planners needing the information. To address these information gaps, the USFS Rocky Mountain Region (Region 2), through its Species Conservation Project, has initiated the development of Species Conservation Assessments for a number of plant and animal species (USDA Forest Service 2004).

Goal

Our goal in this document is to provide a comprehensive and synthetic review of the biology, ecology, and conservation status of the wetland sedge *Carex limosa* L. (mud sedge) in Region 2. Consistent with previous assessments, we address a variety of topics such as the species' taxonomy, distribution, life history characteristics, physiology, and population biology, as well as known habitat relationships. *Carex limosa* only occurs in specific types of wetlands, so unlike previous assessments prepared for upland species, we place particular emphasis on the hydrologic regime and geochemistry of wetlands supporting known occurrences, as these represent key ecological variables driving the structure and function of wetlands. Lastly, we provide an assessment of the conservation status of the species in Region 2, and we suggest possible approaches for future management, research, and monitoring of the species.

Our goal with this assessment is not to make specific management recommendations but rather to synthesize basic knowledge regarding the species, its habitat, and potential threats. Wetlands supporting *Carex limosa* in the northern hemisphere and within Region 2 are functionally diverse, making formulation of specific predictions regarding the direct and indirect effects of management activities on the species impossible. However, the general principles we present provide a useful context for managers to identify, evaluate, and mitigate for the potential impacts of management actions.

Scope of Assessment

In this assessment, we detail current knowledge regarding the biology, ecology, conservation status, and management of *Carex limosa* in USFS Region 2, which encompasses 17 national forests and seven national grasslands throughout Colorado, Kansas, Nebraska, South Dakota, and Wyoming. For this assessment, Region 2 refers to all lands within the general administrative boundaries of the USFS Rocky Mountain Region, regardless of ownership or management. However, because much of the literature available for *C. limosa* comes from outside of Region 2, data and information from a broader geographic area are included where appropriate. Likewise, while the temporal scope of the assessment is on current conditions, we also include relevant information from historical and evolutionary perspectives.

Information Sources

Considering the broad scope of this assessment, both topically and geographically, we have drawn upon a wide variety of information sources. These include qualitative and quantitative sources, ranging from the peer-reviewed literature to informal discussions with managers and scientists familiar with the species, its habitat, or potential management threats. Where available, we have incorporated quantitative data, such as hydrology, vegetation, or water chemistry parameters from wetlands known to support *Carex limosa* occurrences. Relatively few peer-reviewed studies directly pertaining to *C. limosa* have been published from the region. Consequently, we also drew from the more extensive ”gray literature”, such as unpublished reports and graduate theses and dissertations, as well as from studies conducted outside of Region 2.

Treatment of Uncertainty

Ecological systems and the biota inhabiting them are, by nature, exceedingly complex and unpredictable. Typically, multiple variables influence any given ecological attribute, whether it be community composition, biogeochemical cycling rates, or patterns of species invasion, persistence, or extinction. Important variables are frequently strongly interdependent and difficult to isolate and effectively measure, complicating data collection and analysis. Moreover, ecological patterns and processes are frequently strongly scale dependent. For instance, generalizations appropriately made at one scale may not be appropriate at other larger and/or smaller scales.

When preparing broad-scale assessments such as this, where rigorous, quantitative data are largely unavailable, it is important to explicitly address issues of uncertainty and to draw upon whatever substantive forms of information are available. In this assessment, we have placed the greatest weight upon information gleaned from the peer-reviewed scientific literature; however, we have also relied upon the impressions and ideas of scientists and managers familiar with the species or its habitats. These more informal information sources are cited in the text as personal communication.

Publication of Assessment on the World Wide Web

To facilitate their use in the Species Conservation Project, species assessments will be published on the USFS Region 2 World Wide Web site (http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml). Placing documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More importantly, Web publication facilitates revision of the assessments, which will be accomplished based on guidelines established by USFS Region 2.

Peer Review

Assessments developed for the Species Conservation Project have been peer reviewed prior to release on the Web. This assessment was reviewed through a process administered by the Center for Plant Conservation, employing two recognized experts on this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Because *Carex limosa* is widely distributed throughout the northern hemisphere, NatureServe (2004) has given the species a global conservation rank of G5, globally secure. The species is unranked at the national level (NNR) in both the United States and Canada. *Carex limosa* is neither listed nor proposed for listing under the U.S. Endangered Species Act. However, the states of Connecticut, New Jersey, and Ohio have listed the species as endangered under state law, and Pennsylvania has listed the species as threatened. The conservation rating in individual states and Canadian provinces is variable, ranging from S5 to S1 (**Table 1**).

Table 1. Conservation status of *Carex limosa* L. (Cyperaceae) by state and Canadian province. See glossary for Natural Heritage Program ranks. USDA Forest Service Region 2 states are in bold and italics. (NatureServe 2004).

State	Status	State	Status	Province	Status
Alaska	SNR	Nevada	SNR	British Columbia	S4
California	S3	New Hampshire	SNR	Labrador	S3S5
Colorado	***S2***	New Jersey	S1	Manitoba	S5
Connecticut	S1	New Mexico	SNR	New Brunswick	SNR
Delaware	SX	New York	SNR	Newfoundland Island	S3S5
Idaho	SNR	North Dakota	S2	Northwest Territories	SNR
Illinois	S1S2	Ohio	S1	Nova Scotia	S4
Indiana	S1	Oregon	SNR	Nunavut	SNR
Iowa	S1	Pennsylvania	S2	Ontario	S5
Maine	SNR	Rhode Island	SH	Prince Edward Island	S2
Massachusetts	SNR	Utah	S3	Quebec	SNR
Michigan	SNR	Vermont	SNR	Saskatchewan	SNR
Minnesota	SNR	Washington	SNR	Yukon Territory	SNR
Montana	SNR	Wisconsin	SNR	Alberta	S4
Nebraska	***S1***	***Wyoming***	***S2***		

Natural Heritage programs in both Wyoming and Colorado have given *Carex limosa* a rank of S2, indicating the species faces a moderate threat of extinction at the state level because of a low number of occurrences. The Nebraska Natural Heritage program lists *C. limosa* as a species of special concern and has ranked the species as S1. Because of its limited distribution within Region 2, the species has been considered for listing as a USFS sensitive species. However, based largely on the responses of biologists from the six Region 2 national forests known to support the species, the regional office has determined that there is insufficient information to warrant listing (USDA Forest Service 2003). Although there are no data suggesting that specific occurrences are declining, few quantitative studies are available documenting the condition or trend of occurrences. The habitats supporting the species are generally sensitive to a range of impacts, and consequently, the species' status within Region 2 needs to receive periodic review as more information is found.

Existing regulatory mechanisms, management plans, and conservation strategies

Carex limosa is not listed as either threatened or endangered under the Endangered Species Act, nor has the USFS Region 2 granted the species sensitive status. Consequently, no specific regulations concerning the conservation of the species apply. As an obligate wetland species *sensu* Reed (1997), *C. limosa* and its habitat receive limited protection under some existing federal, state, and local statutes. Section 404 of the Clean Water Act has historically placed regulatory oversight on a range of activities impacting wetlands with the U.S. Army Corps of Engineers (USACE). However, the Supreme Court's decision in Solid Waste Agency of Northern Cook County (SWANCC) vs. USACE has effectively removed the USACE's regulatory oversight for wetlands that lack connections to surface water bodies such as streams. Most fens lack surface water connections to navigable waters of the United States and may therefore be considered isolated with regards to USACE jurisdiction under the Clean Water Act (Bedford and Godwin 2003). However, the scope of USACE jurisdiction on geographically isolated wetlands is still undetermined, with cases still under review in the courts. Also relevant to wetlands management on National Forest System lands is Executive Order 11990; this order instructs agencies to "take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands."

Within Region 2, the Watershed Conservation Practices Handbook (FSH 2509.25) sets standards and guidelines to meet state water quality standards and to conserve watershed processes, streams, and wetlands. Specific regional guidance on fens is provided by USFS memo 2070/2520-72620, signed by the Director of Renewable Resources, which emphasizes the protection, preservation, and enhancement of fens to all Region 2 forest supervisors (Proctor personal communication 2004). However, the memo is not a directive, and it does not limit the kinds of management activities that can be pursued in wetlands supporting *Carex limosa*.

Biology and Ecology

Classification and description

Systematics and synonymy

Carex limosa was one of nearly 30 species Carl Linnaeus assigned to the genus *Carex* in his first edition of *Species Plantarum* in 1753. Since then, more than 2,000 species have been described globally, including more than 500 in North America (Ball and Reznicek 2004). Species in the genus *Carex* are similar morphologically, and many are largely indistinguishable by vegetative characteristics alone (Metcalfe 1969), making sedge taxonomy difficult and field identification impossible if plants are not fruiting. At the subgenus level, most authors in North America have followed Mackenzie's (1940) arrangement of the genus (Ball and Reznicek 2004), in which he divided North American *Carex* into 71 sections delineated principally on gross morphology. Many sections may not be monophyletic, and revisions of Mackenzie's original grouping have been suggested (Reznicek 2001). However, these changes have not resulted in a change in the sectional treatment of *C. limosa*, and it remains the lectotype species for the Section *Limosae* (**Table 2**).

Morphological characteristics

Carex limosa is a clonal, perennial sedge 20 to 60 cm tall (**Figure 1**). The culms are slender, reddish, and sharply triangular in cross-section. The basal leaves are typically greatly reduced in size (aphyllopodic), and old leaves are persistent. Plants have one to three deeply channeled, glaucous, gray-green leaves 1 to 2.5 mm in width. Leaf margins are involute while leaf sheaths are thin, ventrally hyaline, and shallowly concave at the mouth (Hurd et al. 1998, Johnston 2001, Ball and Reznicek 2004).

Table 2. Taxonomy and nomenclature of *Carex limosa* L. (Cyperaceae) (John Kartesz - Biota of North America Project (BONAP), University of North Carolina, as cited in ITIS 2004).

Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Liliopsida
Subclass	Commelinidae
Order	Cyperales
Family	Cyperaceae
Genus	*Carex*
Species	*C. limosa* L.

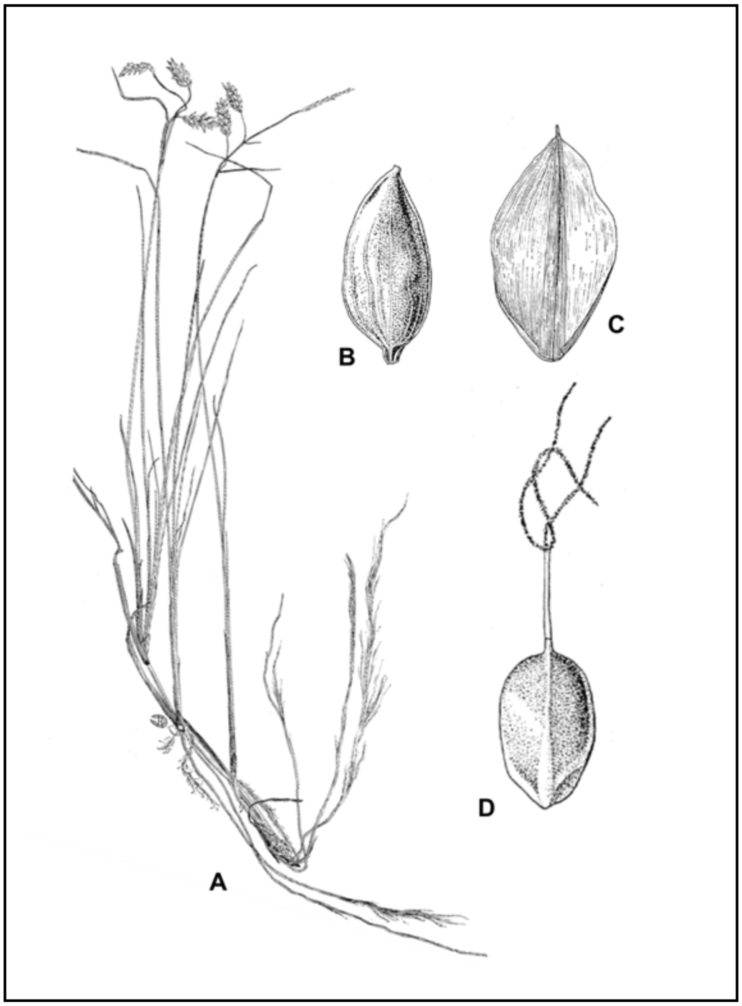

Figure 1. *Carex limosa* L. (Cyperaceae): (**A**) habit, (**B**) perigynium, (**C**) pistillate scale, and (**D**) achene (MacKenzie 1940, used with permission).

Plants have proximal bracts 2 to 6 cm in length, shorter than and subtending the flowering spikes. Lateral inflorescences, which are sometimes androgynous, measure 6 to 20 × 4 to 8 mm; terminal spikes range from 7 to 35 × 1.5 to 2.5 mm. Pistillate scales are ovate-circular in shape, and they are wider and slightly longer than the perigynia, which measure 2.5 to 4 mm long and 1.8 to 2.6 mm wide, and have a rounded apex and a beak 0.1 to 0.5 mm long (Ball and Reznicek 2004).

Carex limosa is similar to the closely related *C. paupercula* (*C. magellanica* Lam. ssp. *irrigua* (Wahlenb.) Hultén.), but it differs in having its lowest leaves strongly reduced to scales and leaves that tend to be channeled (Moseley 1989, Johnston 2001). The closely-related *C. barrattii* Schwein. & Torr. is larger, and unlike *C. limosa*, it has scales that do not cover the sides of the perigynia. Additionally, *C. limosa* has elongate vegetative culms that become stoloniferous while *C. barrattii* spreads clonally exclusively by underground rhizomes.

A considerable portion of growth and biomass is contained in belowground structures. For example, in a Swedish peatland, Sjörs (1991) found that over 70 percent of the phytomass for *Carex limosa* was below ground; however, much of the biomass was not living tissue. *Carex limosa* is a clonal species spreading largely via underground rhizomes or elongate, stolonifeorus stems. Although no studies characterizing the species' clonal growth form were found in the literature, we have observed in the field that it forms highly interconnected root systems. Clones are comprised of modular units called ramets; collectively, they comprise the genet, which represents the product of a single zygote (Harper 1977, Noble et al. 1979).

Although *Carex limosa* is described in numerous regional floras, particularly useful resources for identification include Hermann (1970), Hurd et al. (1998), Johnston (2001).

Distribution and abundance

Carex limosa is widely distributed at higher latitudes throughout the northern hemisphere. It is most common in boreal regions of Canada, Siberia, and Scandinavia, but its distribution also includes many montane areas in Europe, Japan, Korea, and North America (Hulten 1968). In North America, *C. limosa* is found in 30 U.S. states, from Alaska to as far south as Colorado and Nebraska, as well as 14 Canadian provinces (**Table 1**, **Figure 2**; Hulten 1968, Ball and Reznicek 2004, NatureServe 2004, Natural Resources Conservation Service 2004). Though it is broadly distributed, occurrences outside of boreal regions are typically uncommon or rare, reflecting the lower abundance of suitable peatland habitat. It is interesting to note that the distribution of *C. limosa* closely matches that of peat-forming ecosystems in North America.

Globally, *Carex limosa* is found across a broad elevational range, from near sea level to over 3,600 m (11,811 ft.). With the exception of occurrences in the Sandhills region of Nebraska, occurrences in Region 2 are confined to relatively high elevations, where local climate and physiography promote the development of peatlands. The stable, consistently high water tables necessary for peat accumulation are essential to *C. limosa*, and they occur only in favorable microclimatic and hydrogeomorphic settings (Cooper and Andrus 1994, Chimner et al. 2002), which are limited in extent within Region 2. Elevations of fens known to support *C. limosa* in Region 2 range from approximately 2,012 to 3,549 m (6,600 to 11,643 ft.) in Colorado and Wyoming and from 884 to 1,077 m (2,901 to 3,534 ft.) in Nebraska.

Population trend

No reliable region-wide population estimates are available for *Carex limosa*. Because of its clonal habit, definition and field identification of genetically distinct individuals (i.e., genets) of this species is difficult, as the culms comprising a particular *C. limosa* stand may be composed of any number of genetically identical clones. Population estimates made as part of future monitoring activities need to recognize this key aspect of the life history of *C. limosa*.

Habitat

In Region 2, *Carex limosa* typically occurs in montane or subalpine peatlands, often as part of a floating mat community adjacent to an open water system (Cooper 1990, Fertig and Jones 1992). Soils are consistently wet throughout the season, with the water table at or near the soil surface. Although fens supporting *C. limosa* in Colorado and Wyoming occur at relatively high elevations, occurrences have also been found at much lower elevations, as part of the ecologically unique Sandhills fen community type (Steinauer et al. 1996). Although these fens formed in a completely different hydrogeologic setting than the montane fens supporting the majority of Region 2 occurrences, they share stable hydrologic regimes and support a similar compliment of species. Considering *C. limosa*'s broad geographic distribution, the habitats in which this species occurs are remarkably consistent floristically, hydrologically, and biogeochemically (**Figure 3**). For example, common plant associates of *C. limosa* in Colorado fens such as *Menyanthes trifoliata* L. are also noted for sites in Nebraska.

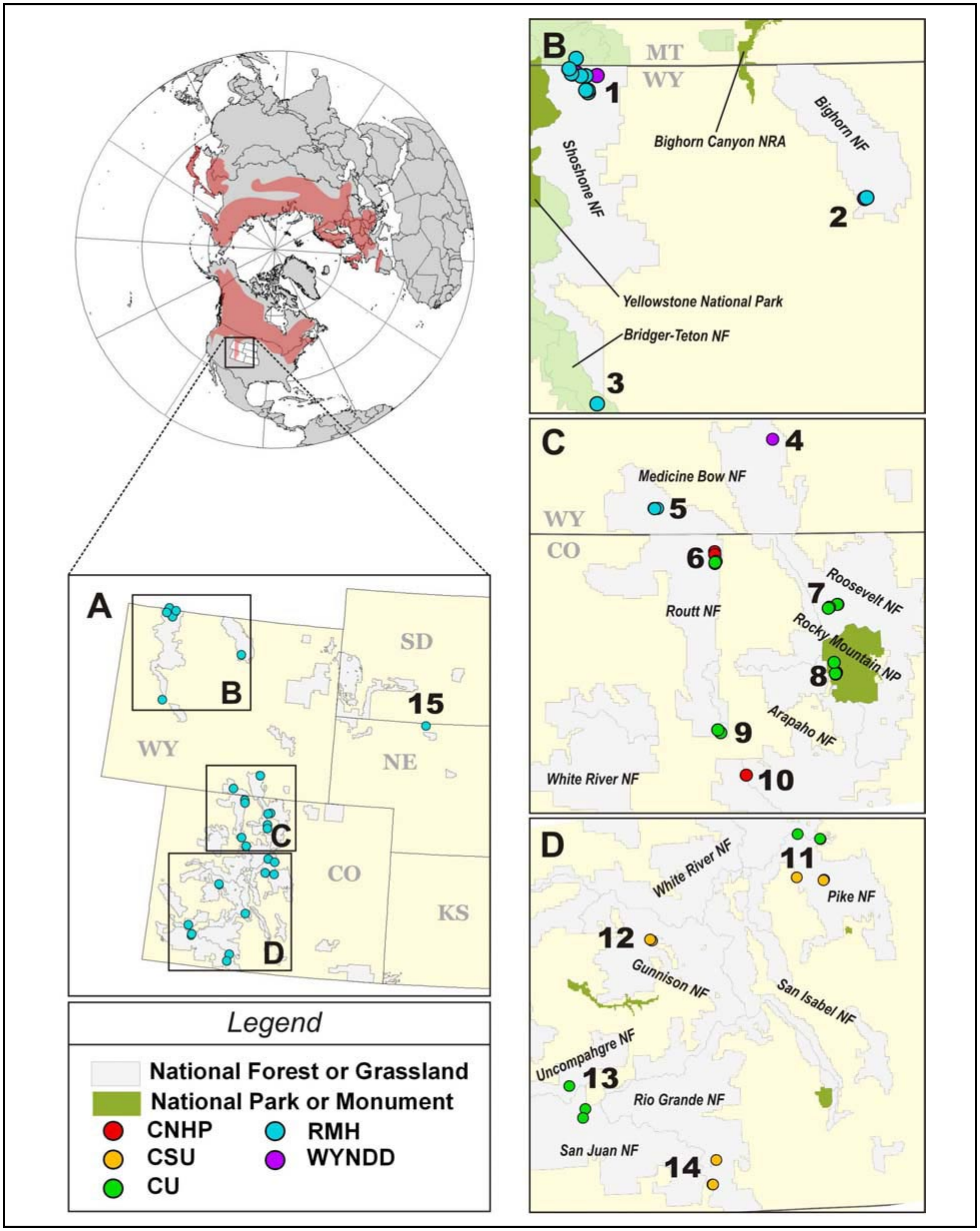

Figure 2. Global and USDA Forest Service Region 2 distribution of Carex limosa L. (Cyperaceae). In panels **B-D**, colors signify different record sources (CNHP = Colorado Natural Heritage Program, CSU= Colorado State University herbarium, CU = University of Colorado herbarium, RMH = Rocky Mountain herbarium, WYNDD = Wyoming Natural Diversity Database). Numbers on map are linked to more detailed record information presented in **Appendix**.

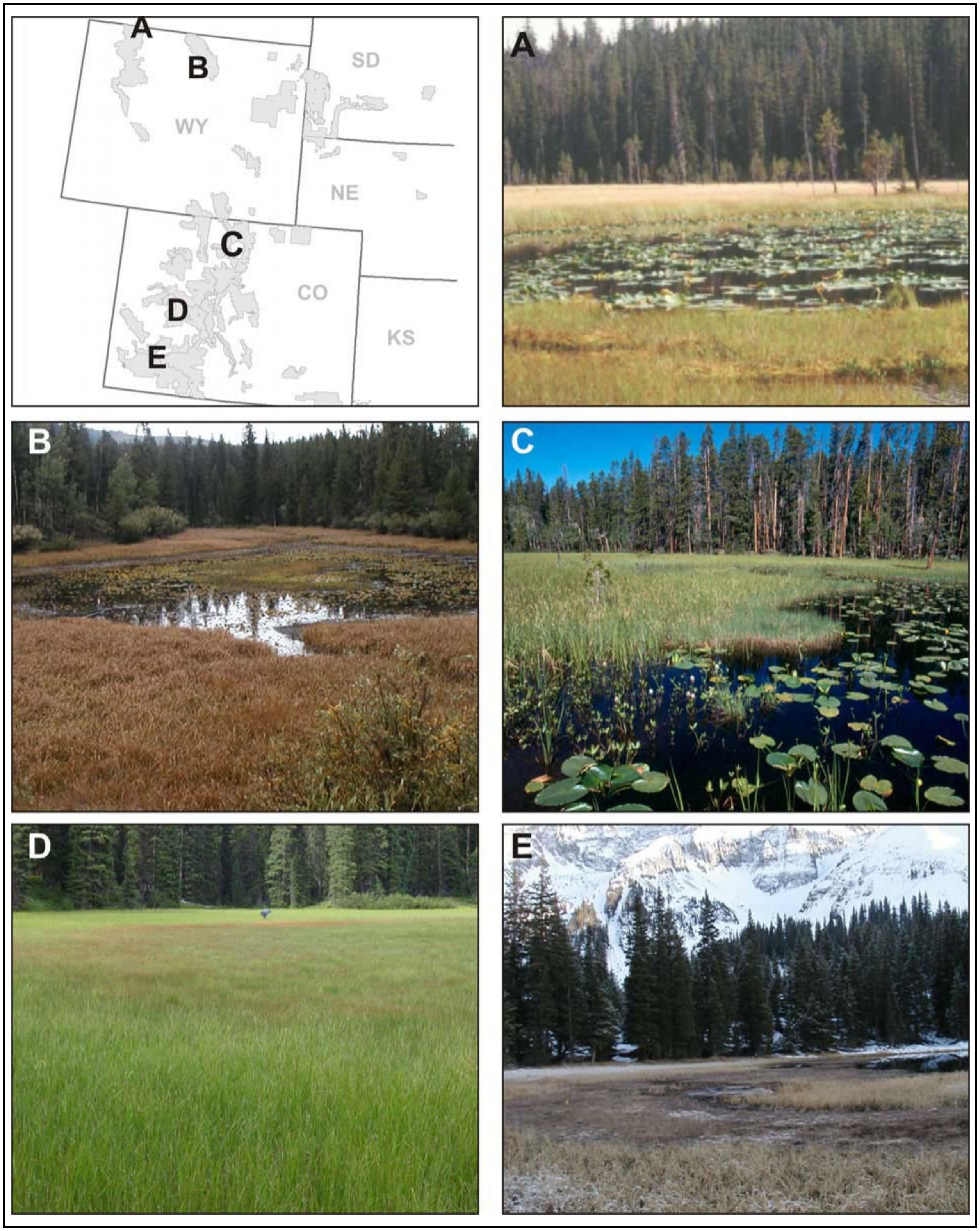

Figure 3. Images of different USDA Forest Service Region 2 fens that support *Carex limosa* L. (Cyperaceae): (**A**) Lily Lake, Shoshone National Forest, WY; (**B**) unnamed kettle pond, Bighorn National Forest, WY; (**C**) Green Mountain Trail Pond, Rocky Mountain National Park, CO; (**D**) Skinned Horse Reservoir, Grand Mesa National Forest, CO; (**E**) Buckbean Fen, San Juan National Forest, CO. (Photograph in panel **A** by W. Fertig, used with permission; panels **B** and **E** by E. Gage, and panels **C** and **D** by D. Cooper).

Reproductive biology and autecology

Life history and strategy

Carex limosa is a perennial sedge establishing from seed or via clonal expansion. There are no studies specifically examining its life history, but other members of the genus have been examined in detail (Bernard 1976, Noble et al. 1979, Bernard 1990), and many of the concepts described for other rhizomatous sedges are expected to apply to *C. limosa*. A general overview of the life cycle of *C. limosa* is presented in **Figure 4**. We have identified four primary stages: (1) seed, (2) seedling, (3) mature plant, and (4) asexual propagule. Researchers working with other clonal sedge species have described up to six distinct age classes. However, since so little demographic data specific to *C. limosa* are available, the utility of such an approach is limited for our assessment.

Reproduction, pollination, and phenology

Members of the genus *Carex*, including *C. limosa*, are wind pollinated (Gleason and Cronquist 1991). No data are available describing out-crossing distances or other basic aspects of *C. limosa* pollination ecology. In the region, *C. limosa* typically flowers between late spring or early summer, and is in fruit from July to August (Hurd et al. 1998).

Seed dispersal, viability, and germination requirements

Carex limosa is capable of establishment from seed under proper environmental conditions. No studies have specifically detailed how *C. limosa* seeds are dispersed, but several agents may be important, including wind (amenochory), water (hydrochory), and animals, specifically birds (zoochory) (Ridley 1930). Seeds may germinate in the spring following dispersal, or they may enter the soil seed bank and germinate when more favorable conditions occur (Leck and Schutz 2005). The relative importance of seed bank processes in *C. limosa* establishment dynamics is unknown.

Few studies examining the seed viability or germination requirements for *Carex limosa* have been conducted, particularly from Region 2. Cambell and

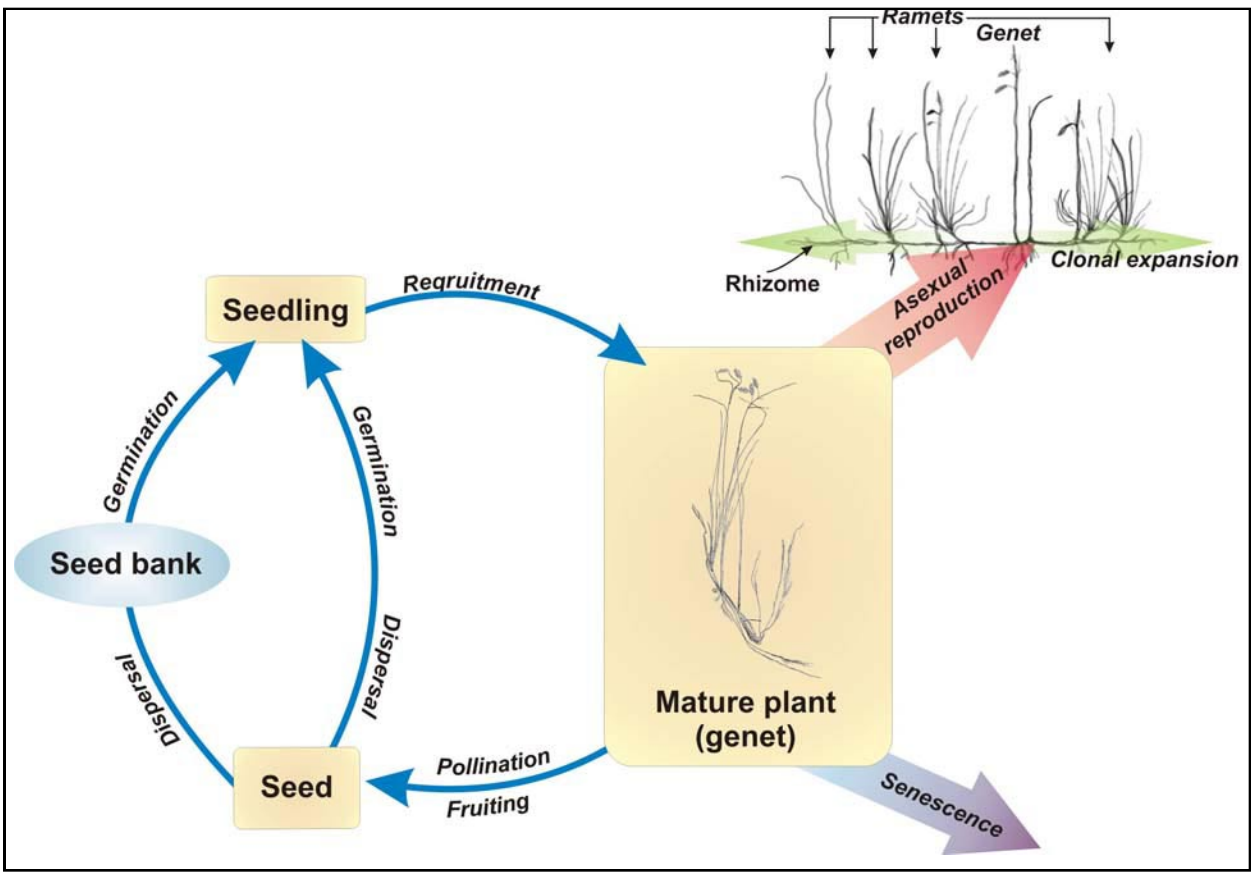

Figure 4. Generalized life cycle diagram for *Carex limosa* L. (Cyperaceae).

Rochefort (2003) compared germination characteristics in relation to seed mass and burial depth for a variety of species, including *C. limosa*. They found that despite their light mass (1.4 mg on average), *C. limosa* seeds were relatively tolerant of burial and were capable of germinating, albeit at reduced rates, even when buried under 15 cm of peat (**Figure 5**; Cambell and Rochefort 2003). However, compared to the other species in their study, *C. limosa* had relatively low seed viability.

A variety of factors can influence rates of seedling growth and thereby influence access to resources, the ability of seedlings to withstand unfavorable conditions, and ultimately, the likelihood of seedling recruitment (Harper 1977). Cambell and Rochefort (2003) measured a wide variety of seedling growth parameters for an assortment of wetland species including *Carex limosa*, and they related these values to survival patterns and found significant correlations between survival and specific leaf area and root length.

Genetic characteristics and concerns

Although we found no genetics research particular to Region 2 *Carex limosa* occurrences, published analyses from outside of the region suggest that *C. limosa* populations show little genetic differentiation even among occurrences from widely separated areas (Vellend and Waterway 1999). Published measures of genetic variability for various northern rhizomatous sedges (**Table 3**) suggest that most species, including *C. limosa*, share a similar level of genetic variability (McClintock and Waterway 1993, Vellend and Waterway 1999). Relative to the other sedge species examined, *C. limosa* has been reported to have slightly lower-than-average levels of genetic diversity within populations and total genetic diversity.

Waterway (1991) also conducted a comparative study of the clonal diversity and genetic variation in nine different *Carex* species commonly found in subarctic fens, including *C. limosa*. The two species with the broadest ecological amplitude, *C. limosa* and *C. rostrata* Stokes, had the largest percentage of unique genotypes per site as well as the highest levels of heterozygosity and polymorphism. Levels of heterozygosity were low in all of the species with restricted habitat preferences. They found that species with long-spreading rhizomes were more polymorphic than the cespitose species or those with only short-spreading rhizomes (Waterway 1991).

The underlying genetic structure of *Carex limosa* occurrences in Region 2 is unknown. Because of the ability of *C. limosa* to reproduce asexually, genetic diversity within individual wetlands may be low, with one or a limited number of dominant genotypes present, as Vellend and Waterway (1999) found for *C. limosa* in eastern North America. It is also unknown to what degree genetic patterns differ among occurrences. Known *C. limosa* occurrences within Region 2 are relatively isolated from one another, so presumably, genetic crossing between occurrences is rare.

Hybridization

Hybridization has been widely reported in the genus *Carex* (Cayouette and Catling 1992). Most verified crosses have been between closely related species within the same section; however, intersectional

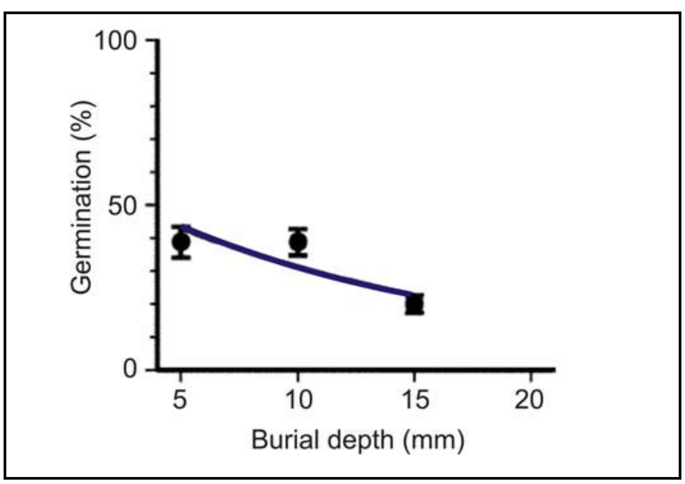

Figure 5. Emergence of *Carex limosa* L. (Cyperaceae) seedlings as a function of seed burial depth (mean ± SE). Emergence is expressed as percent of seeds sown in experiment. Curve represents non-linear regression of emergence rates (Cambell and Rochefort 2003).

Table 3. Measures of genetic variability for northern rhizomatous *Carex* species L. (Cyperaceae) (Vellend and Waterway 1999). *A* is the mean number of alleles per locus, *P* is the number of polymorphic loci per population, H_s is the genetic diversity within populations, H_T is total genetic diversity, G_{ST} is the proportion of total genetic diversity among populations, N_M is gene flow.

Species	*A*	*P*	H_S	H_T	G_{ST}	N_m	Data set	Data source
C. limosa	1.5	42	0.137	0.146	0.063	3.72	genet	Waterway and McClintock (unpublished)
C. saxatilis	1.6	45	0.146	0.182	0.198	1.01	ramet	Ford et al. 1991
C. membranacea	1.6	44	0.162	0.199	0.183	1.12	ramet	Ford et al. 1991
C. rotundata	1.6	44	0.120	0.148	0.184	1.11	ramet	Ford et al. 1991
C. lasiocarpa	1.6	48	0.226	0.266	0.151	1.41	genet	McClintock and Waterway 1993
C. pellita	1.6	44	0.248	0.248	0.181	1.13	genet	McClintock and Waterway 1993
C. bigelowii	1.8	49	0.167	0.180	0.072	3.22	genet	Jonsson et al. 1996
C. paupercula	1.2	19	0.068	0.151	0.553	0.20	ramet	M.J. Waterway and K.A. McClintock (unpublished)
C. rariflora	1.4	32	0.071	0.134	0.467	0.29	ramet	Vellend and Waterway 1999
Mean	**1.6**	**42**	**0.154**	**0.190**	**0.198**	**1.61**		

hybrids have been described. It appears that the majority of crosses produce infertile offspring, but some hybrids are known to produce partially fertile seeds (Cayouette and Catling 1992, Ball and Reznicek 2004).

McIntire and Waterway (2002) used patterns of allozyme polymorphisms to examine the spatial patterns of hybridization between *Carex limosa* and the closely related *C. rariflora* (Wahlenb.) Sm. in Quebec, and to relate these patterns to the incidence of infection by a pathogenic smut (*Anthroacoidea limosa*) (McIntire and Waterway 2002). Even though hybrids were generally sterile, they were able to persist and even expand because of the species' ability to spread clonally. In Canada, *C. limosa* has been reported to hybridize with *C. magellanica* ssp. *irrigua* (Wahlenb.) Hultén, a species co-occurring with *C. limosa* in Region 2 fens, although in distinctly different community types (authors' observation). We found no reports of *C. limosa* hybrids from Region 2, but this may be due in part to a lack of research directed to the question.

Mycorrhizae

Although mycorrhizae are common throughout the plant kingdom, several families including the Brassicaceae, Juncaceae, and Amaranthaceae are considered non-mycorrhizal (Muthukumar et al. 2004). Historically, the Cyperaceae have also been considered non-mycorrhizal; however, research during the past few decades has identified numerous sedge taxa having mycorrhizal associations (Miller et al. 1999). In their recent review of the topic, Muthukumar et al. (2004) identified 88 mycorrhizal sedge species, 40 percent of the 221 sedge species they evaluated. Most instances of mycorrhizal associates were arbuscular mycorrhizae (AM), although they also noted instances of ectomycorrhizal associations. While the status of several *Carex* species was mentioned, *C. limosa* was not among them. Whether *C. limosa* is able to form mycorrhizal relationships, and if so, under what conditions, is unknown.

Demography

Key to understanding a species' population biology is information regarding the important age and life history stages and the nature of the transitions between them. Quantitative data are generally difficult to obtain, particularly for cryptic species or those capable of vegetative reproduction. Unfortunately, few data specific to *Carex limosa* are available, particularly from Region 2 occurrences. As a result, much of our analysis is derived from work conducted on other clonal sedge species and should be thought of as a presentation of hypotheses in need of further research.

Following dispersal and germination, seedlings are recruited into older age classes, but the factors affecting the transition are unknown for *Carex limosa*. Mortality due to herbivory, disease, or competition are possible constraints on recruitment (Harper 1977), but there are no data available to evaluate their relative importance for *C. limosa*. When a ramet matures, it can flower and fruit, produce seed, and initiate the cycle again. Ultimately, senescence of the ramet occurs, unless another mortality agent, such as disease or herbivory, intervenes.

We found no published studies examining the relative phenology and life span of *Carex limosa* shoots; however, work done on several other temperate *Carex* species may provide some insights into their dynamics. In a study of *C. rostrata* in a New York fen, Bernard found that most shoots emerged between mid-summer and early fall, and lasted, at most, 20 to 25 months before senescing (Bernard 1976). Notably, only 17 percent of the shoots he followed survived to produce seeds. Similar results have been reported from Canada for the same species (Gorham and Somers 1973).

The average age of *Carex limosa* genets is unknown, but it could be decades or even millennia (Bernard 1990). In large part because of this species' capability for vegetative growth, the life cycle described above oversimplifies the processes actually driving the age and genetic structure of *C. limosa* occurrences. For example, as a *Carex* clone expands, the connections linking different portions of the clone can be severed, with what was once one clone becoming multiple clones.

Community and ecosystem ecology

Geomorphic and landscape setting

Within Region 2, peatlands have formed in very specific geomorphic and landscape settings that possess the hydrologic and microclimatic conditions conducive to peat accumulation (Windell et al. 1986). These can include sites along slopes where groundwater discharges or in depressions. It is the latter setting that characterizes the fens supporting most *Carex limosa* occurrences in Region 2. For example, in Colorado, Carsey et al. (2003) identified *C. limosa* as an indicator for the D1 HGM subclass, consisting of depressional wetlands found in mid-to-high elevation basins with peat soils or along lake fringes with or without peat soils. These kinds of features are particularly widespread in glaciated terrain, such as areas with high densities of kettle lake basins; these are common in many Region 2 mountain ranges (**Figure 6**). Occurrences in Nebraska are in fens formed in stream valleys, typically adjacent to Sandhills lakes (Steinauer et al. 1996).

Fen formation, development, and succession

Within Region 2, *Carex limosa* most commonly occurs in fens formed in small lake basins or depressions. These are often, but not always, associated with glacial activities. A notable exception are the fens formed in the Nebraska Sandhills, which are associated with groundwater discharge areas in inter-dunal locations (Steinauer et al. 1996). Kettle ponds, formed by stagnant ice left in outwash or morainal material as glaciers retreated, are particularly favorable sites, and are common features in many areas affected by both continental and montane glaciers. In addition, lateral moraines deposited by glaciers have also blocked drainages and produced ponds similar to kettle lakes (**Figure 6**). Mass wasting events, such as landslides, are an additional factor influencing the formation and function of some fens supporting *C. limosa*. Often, sites reflect the influence of both glaciation and mass wasting events (Austin personal communication 2004). Basin size is an important variable influencing hydrology and vegetations, with floating mat *C. limosa* communities most commonly developing in larger and deeper basins (**Figure 7**).

Two general mechanisms are responsible for the formation of peatlands. Terrestrialization is the process by which a water body fills with sediments and peat, and paludification describes the conversion of uplands to peatland through increased waterlogging of soils as developing peat impedes drainage. Terrestrialization appears to be of greater importance in most temperate areas, and within Region 2, fen formation appears to occur exclusively via terrestrialization (**Figure 8**). Because high summer temperatures and low precipitation typically limit peat accumulation rates in Region 2 (Cooper 1990), fens are generally found only at higher elevations, which have cooler and wetter climatic conditions.

Successional processes have been extensively studied in peatlands, but not within Region 2. Both allogenic and autogenic processes have been postulated as drivers of peatland formation, with the relative role of each differing somewhat from wetland to wetland and among different stages of peatland development. Allogenic processes, such as broad scale climatic change, have been hypothesized to be the dominant control on patterns of peatland development. However, the old ages of fen ages obtained by C^{14} dating of peat cores from Region 2 fens suggests that the kinds of climatic fluctuations observed since the last glacial maximum are less important than autogenic processes in driving peatland development (Cooper 1990, Muller et al. 2003).

Cooper (1990) described a general successional pattern for basin fens in the Southern Rocky Mountains, whereby open-water aquatic communities dominated by *Nuphar lutea* (L.) Sm. and *Potamogeton gramineus*

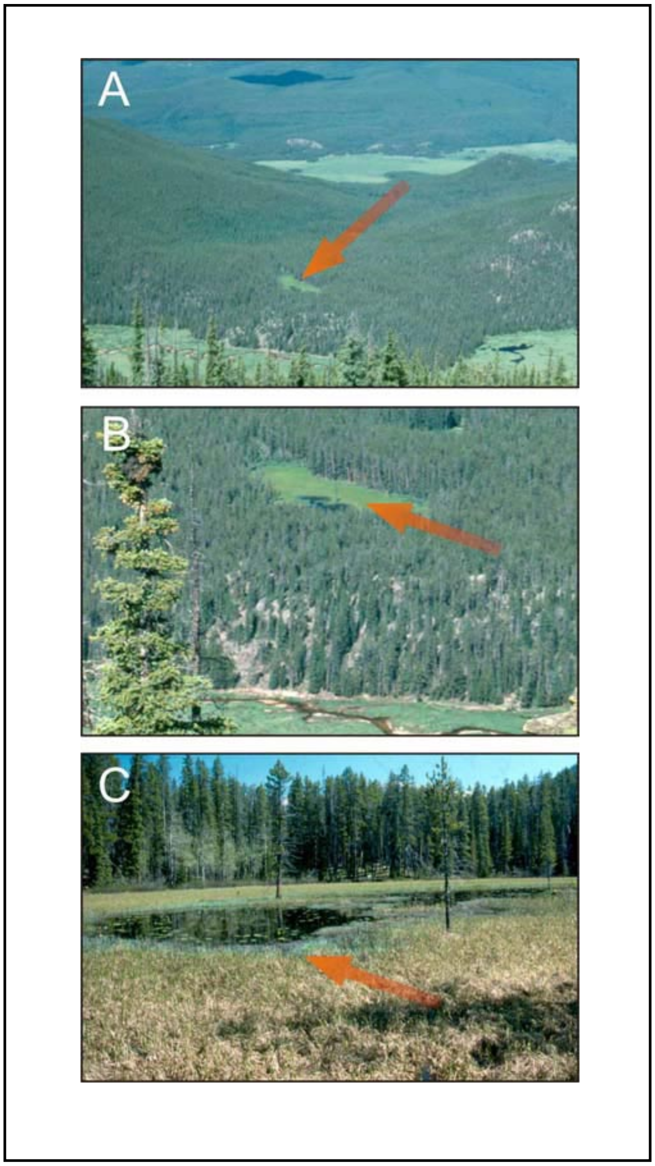

Figure 6. Three photographs, illustrating at different scales, a lateral moraine dammed basin that supports *Carex limosa* L. (Cyperaceae) (indicated by red arrows) (Green Mountain Trail Pond, Rocky Mountain National Park, CO; Photographs by D. Cooper).

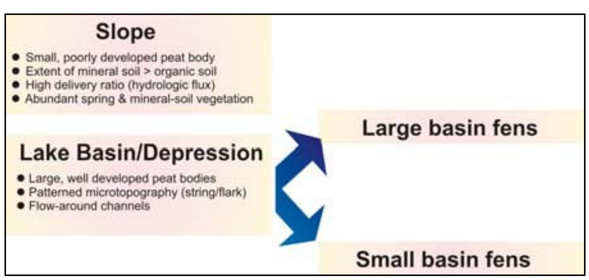

Figure 7. Schematic diagram illustrating one of several ways to classifiy fens. *Carex limosa* L. (Cyperaceae) is tyically associated with fens formed in depressions or lake basins, particualrly large ones (Modified from Cooper and Arp 2002, used with permission).

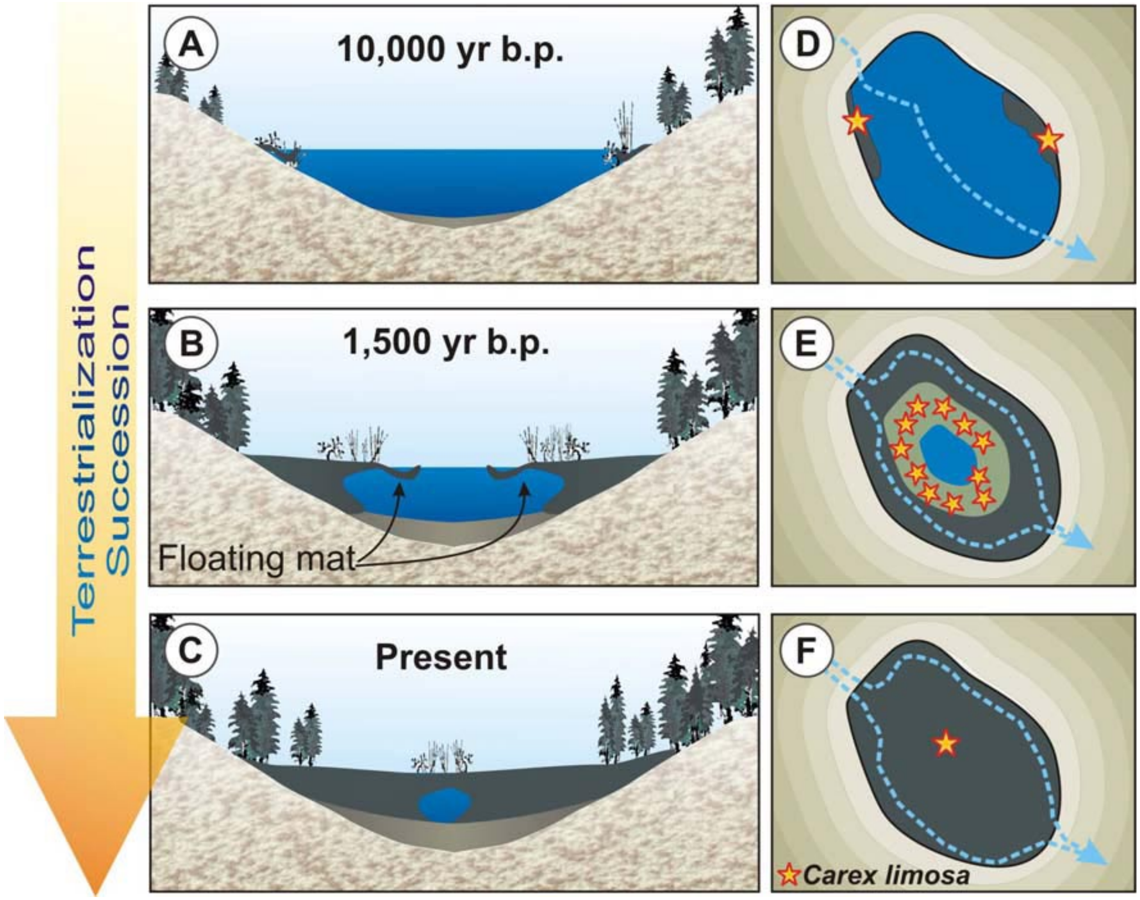

Figure 8. Paired schematic cross-sections (**A-C**) and plan form diagrams (**D-F**) illustrating the geomorphic and successional development of a hypothetical small kettle lake into a sedge-dominated fen. Early in the basin's development, *Carex limosa* L. (Cyperaceae) colonizes the margin of the recently formed kettle lake (**D**). Over time, a floating mat dominated in part by *C. limosa* develops (**B, E**). Ultimately, as terrestrialization continues, the open water environment characteristic of earlier stages is lost. At this stage, competitive displacement of *C. limosa* occurs as the wetland fills making *C. limosa* constrained to only the wettest microsites.

L. proceed through a *Menyanthes trifoliata*-*Carex utriculata* stage, into a *C. limosa* stage, and ultimately, to a *C. utriculata*-*C. canescens* L. community.

Since *Carex limosa* is typically restricted to floating mat environments, which represent a finite stage in the terrestrialization of many small basins, it may be thought of as a mid-seral species. However, because a trademark characteristic of fens is their high hydrologic stability and low frequency of disturbance (Cooper 1990), *C. limosa* may remain a viable component of plant communities for thousands of years.

Substrate characteristics and microhabitats

Carex limosa is most commonly found on either anchored or floating peat mats. The depth of peat underlying *C. limosa* occurrences is highly variable and is driven largely by variation in fen age, basin size (for non-slope peatland types), aspect and elevation, and degree of minerotrophy (**Table 4**).

A variety of distinct micro-topographical features, such as hummocks, ridges (strings), and pools (flarks), can form in fens (Glaser 1987, Foster et al.

Table 4. Elevation, pH, and maximum peat thickness for several fens in the Sierra Nevada that support *Carex limosa* L. (Cyperaceae) occurrences. Mean values are in bold, and standard error values are in parentheses (Cooper unpublished data).

pH	Elevation (m)	Peat thickness (cm)
6.46	1,705	50
6.39	2,067	253
6.03	2,115	140
5.83	2,118	60
5.80	2,147	50
6.59	2,282	100
5.70	2,303	80
5.91	2,639	40
6.08	**2,172**	**96.625**
(0.12)	**(92)**	**(25.18)**

1988, Cooper and Andrus 1994). Water table depth, pH, and cation concentrations can vary considerably among these features, influencing vegetation patterns in these microsites. Generally, *Carex limosa* occupies the wettest, non-aquatic microsites, which can include pools, hollows, or floating mats (Glaser 1987, Cooper and Andrus 1994, Bragazza and Gerdol 1996). For example, working in west-central Alberta, Slack et al. (1980) emphasized the dominance of *C. limosa* in flarks, small pools that are among the wettest microsites in patterned fens.

An additional example is Swamp Lake, an extreme rich fen supporting *Carex limosa* on the Shoshone National Forest. The fen exhibits rather complex microtopography, which helps support many of the rare species found there such as *C. livida*, *C. leptalea*, *C. diandra*, *Sparganium natans* L., and *Kobresia simpliciuscula* (Wahlenb.) Mackenzie (Heidel and Laursen 2003a). Microtopographic features, which have been characterized as strings and flarks, run parallel to the slope and support a distinct flora (Heidel and Laursen 2003a).

Hydrologic regimes

Water table depth is perhaps the single greatest factor influencing vegetation patterns in fens. Mean water table depth and intra and inter-annual hydrologic variability have been significantly correlated with wetland vegetation patterns. For example, using vegetation and environmental data collected from several peatlands, Bragazza and Gerdol (1996) developed response surfaces for a variety of species including *Carex limosa*, which predicted cover values for species based on several physical and chemical variables including water table depth and pH. They found *C. limosa* across a range of pH values; however, the range of water table values was much more limited, from approximately 20 cm in depth to the ground surface (**Figure 9**).

Carex limosa is generally found in the most stable and wet sites hydrologically. This is particularly the case with floating mat systems, which are able to rise and fall with changing water levels (**Figure 10**). Although the floating mat environments can function rather simply hydrologically, overall hydrologic patterns in fens can be significantly more complex, with surface and groundwater from various sources affecting water table levels. For example, Swamp Lake on the Shoshone National Forest is supported by several sources, including toe slope seeps and springs, surface flow entering the fen, subsurface flow entering through adjacent debris fans, and groundwater discharge that emanates from glacial deposits on the margins of the fen (Heidel and Laursen 2003a).

Nutrients, water and peat chemistry

As applied to fens, the terms poor and rich have typically been used to describe wetland fertility gradients, specifically nitrogen and phosphorus availability (Bragazza and Gerdol 2002), as well as species richness gradients (DuRietz 1954). Concentrations of mineral ions such as calcium (Ca^{2+}) and pH are generally thought to co-vary with nutrient-availability gradients, although some researchers suggest that pH and nutrient gradients should be separated (Bridgham et al. 1996, Wheeler and Proctor 2000, Bragazza and Gerdol 2002). However, within North American peatlands, most studies have found a close correlation between cation concentrations and pH, so either can be effectively used to characterize habitat.

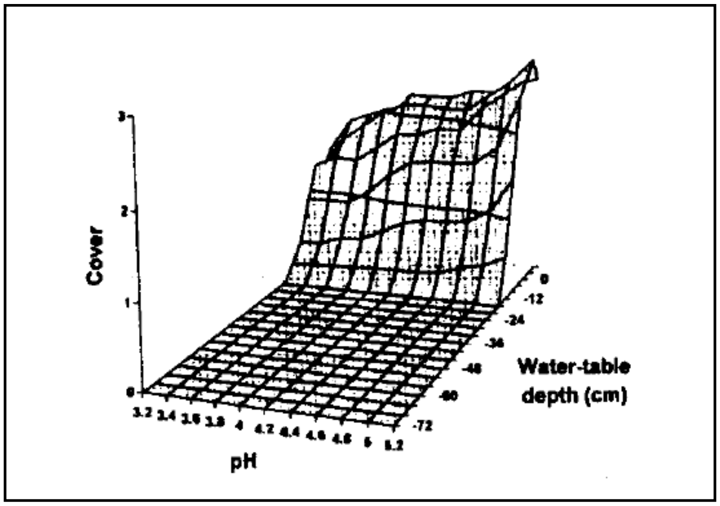

Figure 9. Response surface predicting cover (in cover classes) for *Carex limosa* L. (Cyperaceae) in relation to water table depth and pH. (Bragazza and Gerdol 1996).

Carex limosa is found across a wide range of pH values. For example, Vitt and Slack (1975) and Schwintzer (1978) found *C. limosa* in alkaline lake-margin communities while Anderson et al. (1996) reported *C. limosa* from Maine peatlands with an average pH of 4.3. In Minnesota, Glaser (1987) found *C. limosa* in ombrotrophic bogs and extremely poor fens, with pH as low as 3.7, as well as in spring fed channel and flark sites with a pH near 6.8. Within Region 2, wetlands supporting *C. limosa* occurrences similarly exhibit a wide range of pH values (**Figure 11**). For example, the Swamp Lake site on the Shoshone National Forest has circum-neutral to alkaline pH values characteristic of extreme rich fens (Heidel and Laursen 2003a). Fertig and Jones (1992) measured pH values of 6.9 to 7.9 while pH measurements taken at calcareous springs at the site ranged from 8.0 to 8.4 (Heidel and Laursen 2003a). The Swamp Lake *C. limosa* community occurs under more alkaline conditions than most of the other Region 2 fens and lacks the floating *Sphagnum* mats commonly seen in many of these other sites (Heidel and Laursen 2003a). In contrast, the occurrence at Buckbean Fen on the San Juan National Forest occurs in a more acidic environment typical of poor to intermediate rich fens (Cooper and Arp 2002), the most common types of fens in the region. As an additional example, Cooper and Andrus (1994) found pH and ion concentration values ranging from 5.9 to 6.8 in a fen supporting *C. limosa* in the Wind River Range of Wyoming.

Nitrogen is typically the limiting nutrient for terrestrial plants, but phosphorus may be limiting in some environments (Mitsch and Gosselink 2000). For example, total net primary productivity has been correlated with NO_3^- and total phosphorus surface water concentrations (Beltman et al. 1996, Thormann and Bayley 1997). Biologically-mediated redox reactions account for the principal fluxes of nitrogen in wetlands, such as nitrate reduction, nitrogen (N_2) fixation, and denitrification (Beltman et al. 1996, Oien 2004). The bacterial flora largely responsible for these transformations differs depending on site-specific hydrologic and chemical characteristics. Anoxic sites, as typified by floating mat environments, typically have low total nitrogen low nitrate (NO_3^-) due to a lack of nitrifying bacteria (**Figure 12**).

Considerable variation in the concentration of cations in fen water and peat is also common. Differences among fens are largely the result of different bedrock geology and hydrology (Windell et al. 1986). It is also common to see large differences within microsites in individual fens (Cooper and Andrus 1994). **Table 5** presents data from two adjacent fens in the San Juan Mountains that support *Carex limosa*. Although surface water concentrations of the main mineral ions are similar, data from the ion exchange resin bags, which provide an integrated, seasonal measure of nutrient flux in a site, demonstrate greater differences. These are likely due to differences in the flow-through rate of surface water and groundwater in the individual sites.

Sediment dynamics

Relative to other wetland types, peatlands typically have very small sediment flux rates. Because of the slow peat accumulation rates typifying fens in

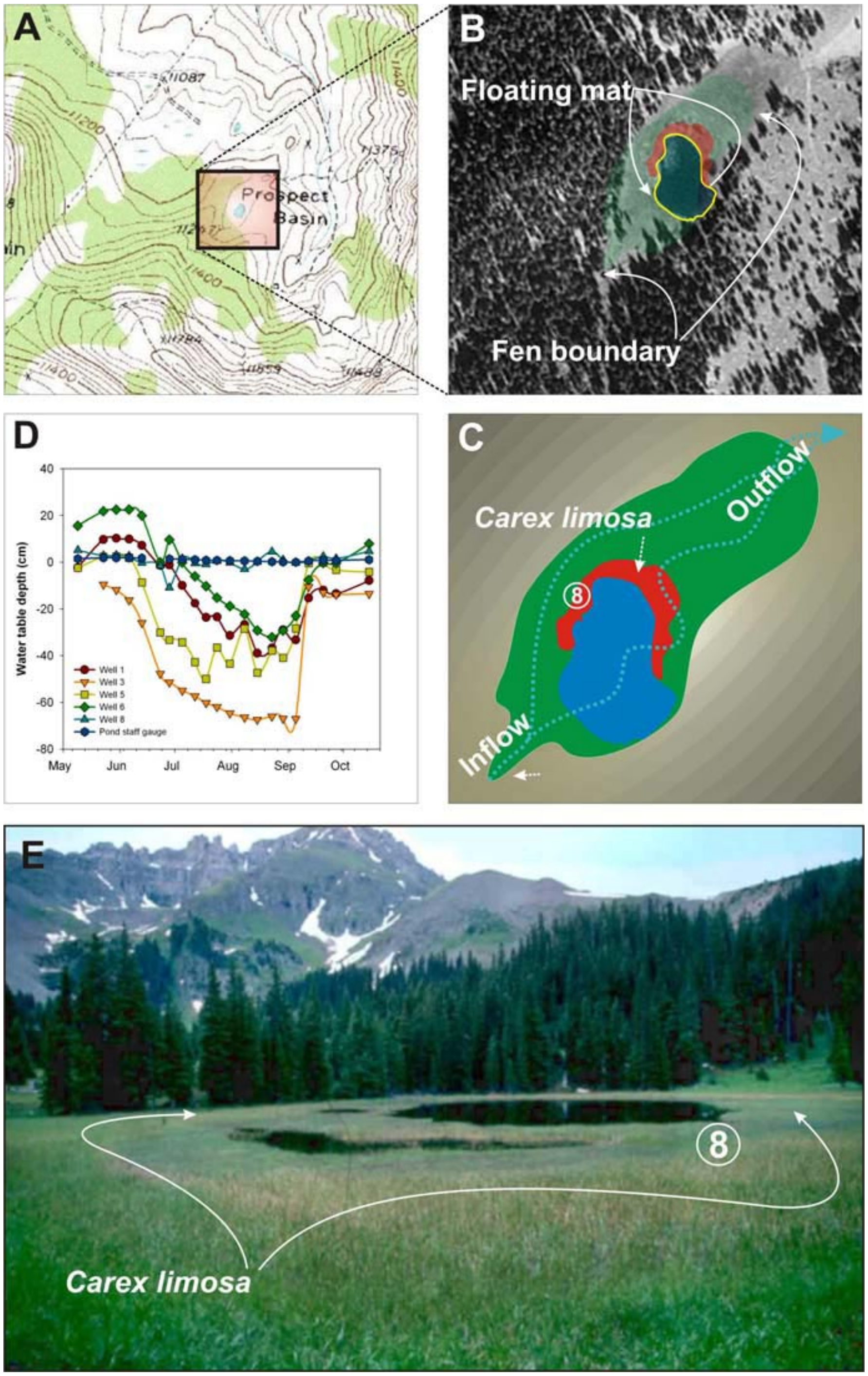

Figure 10. Various representations of Buckbean fen (San Juan National Forest, CO), a small fen that supports a floating mat community dominated by *Carex limosa* L. (Cyperaceae) and Menyanthes trifoliata. The fen has formed in a small, glaciated lake basin and is part of a complex of 5 fens differing in age, basin size, depth, contributing area, and floristic composition (panel **A**). *Carex limosa* is largely limited to the floating mat, identified in panels **B**, **C**, and **E**. Data from monitoring wells in the fen are presented in panel **D**. Well 8 is found within the *C. limosa* community (approximate location indicated in panels **C** and **E**); its hydrograph is remarkably stable relative to the seasonal water table fluctuations characteristic of the other wells. Its stability, despite fluctuations of pond stage, reflects the ability of floating mats to move up or down as water levels change (photograph by D. Cooper).

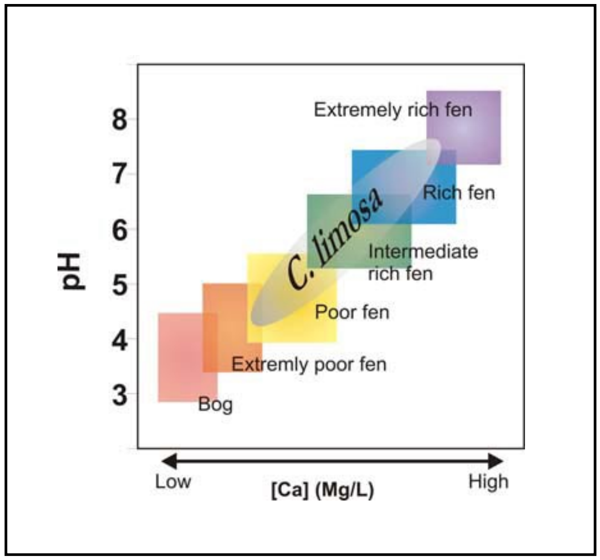

Figure 11. Approximate pH and Ca^{2+} values for different peatland types. Shaded area corresponds to the approximate habitat range of *Carex limosa* L. (Cyperaceae) in USDA Forest Service Region 2.

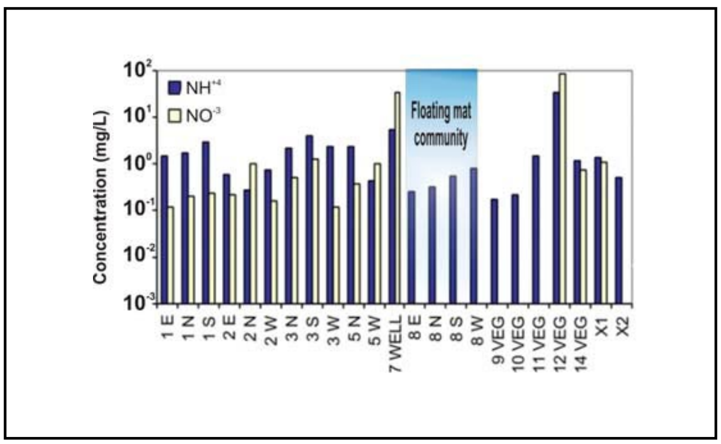

Figure 12. Concentration of ammonium and nitrate ions collected from various sites within Buckbean Fen (San Juan National Forest, CO), a fen that supports *Carex limosa* L. (Cyperaceae). Wells **8 E**, **8 N**, **8 S**, and **8 W** are all located within a *C. limosa* community on a floating peat mat. The lack of NO_3^- is typical of sites such as floating mats where the water table is perennially at or near the peat surface, preventing nitrification.

Region 2, significant increases in mineral flux outside of the historic range of variability have the potential to negatively impact vegetation. Although few studies have examined sediment budgets for peatlands, some data are available from fens in the San Juan National Forest (Cooper and Arp 2002).

Using sediment fences placed around the margins of fens and disks placed in the fen interior, Cooper and Arp (2002) quantified the delivery of mineral sediment and organic material (e.g. twigs, cones, spruce needles) to fens. Sediment deposition in 2001 following spring runoff averaged 62 g per m^2 (0.013 lb. per ft.^{2}) with <0.1 mm of accretion, versus 13 g per m^2 (0.003 lb. per ft.^{2}) in 2000. Sediment in both years was over 60 percent organic matter by weight, suggesting that adjacent forest communities contribute significant amounts of organic matter into fens. However, virtually no sediment was delivered to the interior of fens, where *Carex limosa* is found, suggesting that these communities may be insulated somewhat from changes in sediment fluxes at the margins of fens.

Vegetation types and associated plant species

Wetland vegetation patterns, particularly in peatlands, can be highly variable. Species diversity within individual plant communities is often low;

Table 5. Mean water chemistry parameters (SE in parentheses) from Buckbean and String fens, San Juan National Forest, CO, two adjacent fens that support *Carex limosa* L. (Cyperaceae), and were formed in basins of different size and morphology (Cooper and Arp 2002).

Site	pH	Conductivity (mS/cm)	Mean Concentration (mg/L)			Ion Exchange Bags (mg/L)	
			Ca^{+2}	Mg^{+2}	HCO_3-	Ca^{+2}	Mg^{+2}
Buckbean							
Fen	6.3	18	2.94	0.23	18.4	8.1	1.3
	(0.2)	(3)	(1.15)	(0.06)	(5.6)		
Inflow	6.1	16	1.98	0.23	17.8	86.8	15.6
	(0.4)	(4)	(0.83)	(0.12)	(5.3)		
Outflow	6.4	17	2.02	0.27	10.0	40.2	8.4
	(0.1)	(1)	(0.98)	(0.08)	(0.9)		
Spring	6.9	92	24.20	1.16	70.7		
	(0.1)	(6)					
String							
Fen	6.1	31	5.09	1.00	23.7	22.4	8.0
	(0.2)	(4)	(1.8)	(0.17)	(2.7)		
Inflow	7.6	37	5.07	1.18	25.7	93.0	18.7
	(0.1)	(2)	(2.08)	(0.27)	(6.8)		
Outflow	7.4	35	5.63	1.39	27.5	82.1	20.0
	(0.1)	(3)	(1.68)	(0.09)	(4.3)		

however, strong hydrological and chemical gradients, key in determining the fine-scale distribution of individual species, often create multiple, distinct vegetation zones dominated by completely different suites of species (**Figure 13**). Thus, relatively high species diversity can be seen at the scale of the entire wetland.

Typically, species diversity is lowest in nutrient poor systems, such as bogs and poor fens, and in microsites characterized by either extremely wet or acidic conditions. The communities that *Carex limosa* dominates typically are species-poor, and often *C. limosa* is one of a small number of vascular plant species present. Some of the most common associates, both globally and in Region 2 fens, are *Menyanthes trifoliata* (buck bean), *Eriophorum angustifolium*, and other sedges (e.g., *C. lasiocarpa*, *C. livida*). Bryophytes associated with *C. limosa* can vary, with more acidic poor fens and intermediate rich fens supporting *Sphagnum* species while circum-neutral and basic systems supporting "brown moss" species (Vitt and Bayley 1984, Wells 1996, Anderson and Davis 1997, Hotes et al. 2001).

Though widespread geographically, the communities that *Carex limosa* occupies have a remarkably similar floristic composition and function, whether in Colorado or Korea. Although methodological and regional floristic differences can make cross-walking among different vegetation classifications difficult, there are obvious similarities in the community types in which *C. limosa* is found. For example, Sjörs (1991), working in a rich fen in Sweden, described a community dominated by *C. limosa* and *Menyanthes trifoliata*. This same plant association appears to be circumboreal in distribution and is referred to as a *Caricetum limosae* in the Braun-Blaquet classification method (Heidel and Laursen 2003a).

In North America, Chadde et al. (1998) described a *Carex limosa* community type for the inland Northwest, which appears to correspond to the *C. limosa* /"Brown moss" and *C. limosa* /*Sphagnum* herbaceous community types described by Cooper and Jones (2004) from Montana. Examples of similar vegetation associations from Region 2 include Cooper (1990), Heidel and Laursen (2003a, 2003b), Girard et al. (1997), Carsey et al. (2003), Cooper and Andrus (1994), and Mattson (1984) (**Table 6**).

The Nature Conservancy uses the term "ecological system" to refer to an assemblage of biological communities found in sites with similar

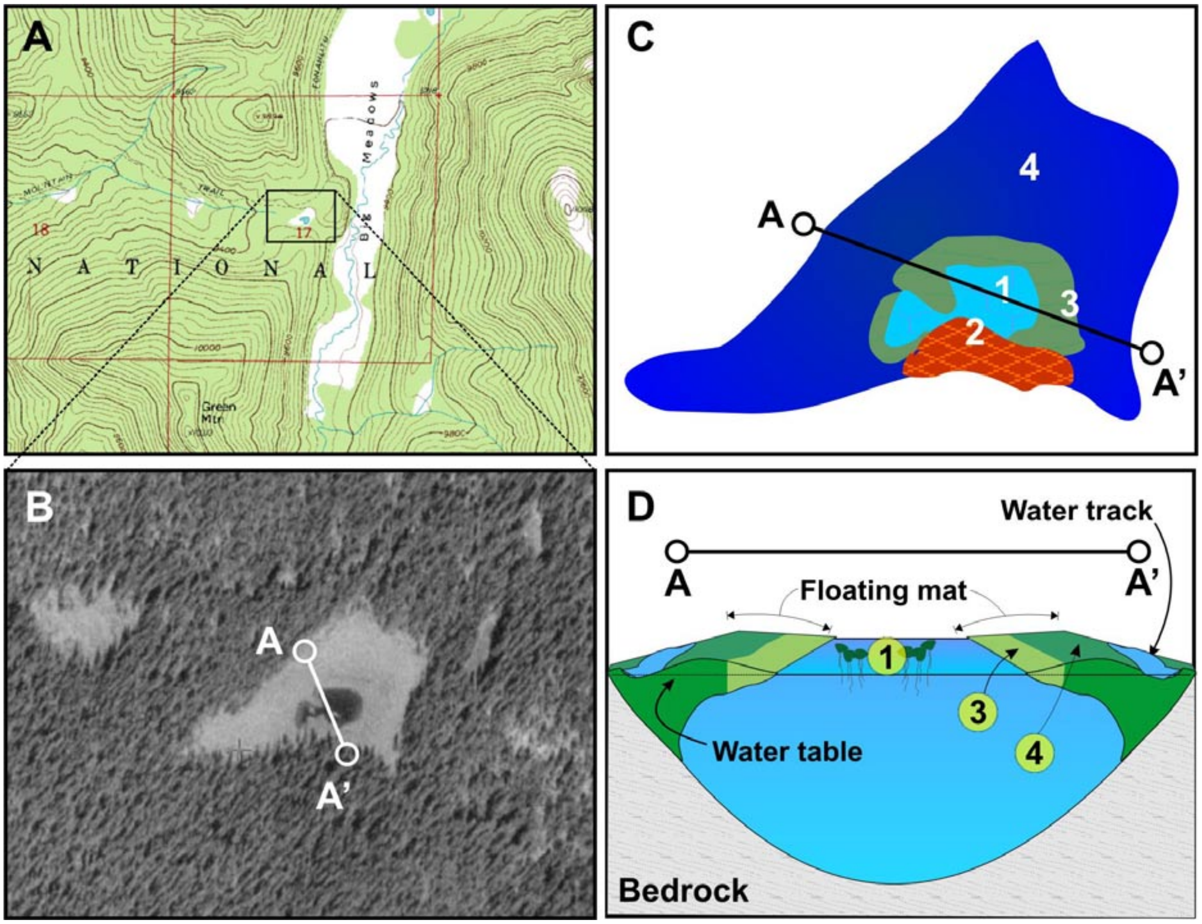

Figure 13. Vicinity map (**A**) and aerial photograph (**B**) of the Green Mountain Trail Pond, Rocky Mountain National Park, CO. Numbers in panels C and D refer to the principle plant communities described by Cooper (1990). A *Carex limosa* L. (Cyperaceae) community is labeled as no. 3 in panels **C** and **D**; note that boundaries are distinct between communities.

physical environments, disturbance regimes, underlying environmental features (e.g., acidic water chemistry, peat soils), or environmental gradients (Comer et al. 2003a). Ecological systems data are coarser in scale than either alliance or plant associations, which represent the finest classification units defined by the National Vegetation Classification system. In their analysis of Ecological Systems in Region 2, Comer et al. (2003b) described a *Carex limosa* seasonally flooded herbaceous alliance as occurring in two ecological systems: the Rocky Mountain Subalpine Montane Fen herbaceous wetland ecological system (CES306.831) and the Rocky Mountain Alpine-montane wet meadow herbaceous wetland system (CES306.812). These systems occur infrequently throughout higher elevations in the Rocky Mountains where certain hydrologic, geomorphic, and climatic factors are present.

Competitors and relationship to habitat

Carex limosa is nearly always found in open, unshaded sites. Anderson et al. (1997) found *C. limosa* only in completely shadeless environments in Maine. In England, ecologists assigned an Ellenberg indicator value for light of 8 on of a scale from 0 to 10, indicating that the species is a light-loving plant rarely found where relative illumination in summer is less than 40 percent (Hill et al. 1999). These results suggest that *C. limosa* may be unable to effectively compete with other larger sedge species and is only an effective competitor in the extremely wet microsites in which it is typically found.

Table 6. Common plant associates of *Carex limosa* L. (Cyperaceae), as reported in a sample of studies from USDA Forest Service Region 2 and elsewhere.

Location	Source	Associated species
Region 2		
Colorado, Rocky Mountain National Park	Cooper 1990	*Carex utriculata* Boott, *Menyanthes trifoliata* L.
Colorado, San Juan National Forest	Cooper unpublished	*Carex utriculata*, *Eriophorum angustifolium* Honckeny, *Menyanthes trifoliata*, *Comarum palustre* L., *Sphagnum fimbriatum* Wils. in Wils. & Hook. f. in Hook. f.
Wyoming, Bighorn National Forest	Girard et al. 1997	*Carex hallii* Olney, *C. rostrata* Stokes, *Deschampsia cespitosa*
Wyoming, Shoshone National Forest	Walford.et al. 1997	*Carex aquatilis*, *Menyanthes trifoliata*, *Pedicularis groenlandica* Retz.
Wyoming, Shoshone National Forest	Heidel and Laursen 2003a	*Menyanthes trifoliata*, *Carex simulata*, *C. utriculata*
North America		
Wyoming, Bridger National Forest	Cooper and Andrus 1994	*Menyanthes trifoliata*, *Comarum palustre*
Wyoming, Yellowstone National Park	Mattson 1984	*Carex aquatilis*, *Menyanthes trifoliata*, *Scorpidium scorpioides* (Hedw.) Limpr., *Eleocharis pauciflora* (Lightf.) Link, *Triglochin maritime* L.
Idaho	Hansen and Hall 2002	*Carex lanuginosa* Michx. var. *americana* (Fern.) Boivin, *C. aquatilis* Wahlenb., *C. livida* (Wahlenb.) Willd., *Calamagrostis stricta* (Timm) Koel., *Drosera anglica* Huds., *Menyanthes trifoliata*
Idaho	Jankovsky-Jones 1997	*Menyanthes trifoliata*, *Carex lasiocarpa* Ehrh., *Betula pumila* L., *C. flava* L., *C. comosa* Boott, *C. utriculata*, *Comarum palustre*
Idaho	Moseley et al. 1991	*Menyanthes trifoliata*, *Drosera anglica*, *Eleocharis pauciflora*, *Carex livida*, *Lycopodium inundatum* L.
Maine	Anderson and Davis 1997	*Sphagnum papillosum* Lindb., *S. magellanicum* Brid., *Rhynchospora alba* (L.) Vahl
Minnesota	Glaser 1987	*Carex lasiocarpa*, *Rhynchospora alba*, *C. livida*, *Scirpus hudsonius*, *Triglochlin maritima*, *Menyanthes trifoliata*
New York	Motzkin 1994	*Menyanthes trifoliata*, *Carex lasiocarpa*, *C. aquatilis*, *Eleocharis* spp., *Myrica gale* L., *Betula pumila*
Canada	Wells 1996	*Sphagnum compactum* DC. in Lam. & DC., *S. warnstorfii* Russ., *Trichophorum caespitosum* (L.) Hartman, *Carex oligosperma* Michx.
Canada	Vitt and Bayley 1984	*Sphagnum papillosum* Lindb., *S. rubellum* Wils., *S. angustifolium* (C. Jens. ex Russ.) C. Jens. in Tolf, *Menyanthes trifoliata*, *Myrica gale*, *Carex lasiocarpa*, *Chamaedaphne calyculata* (L.) Moench
Eurasia		
Japan	Hotes et al. 2001	*Sphagnum fuscum*, *S. magellanicum*, *Myrica gale*, *Eriophorum vaginatum* L., *Menyanthes trifoliata*
Sweden	Sjörs 1991	*Carex lasiocarpa*, *Menyanthes trifoliata*, *C. livida*, *C. rostrata*, *Eriophorum angustifolium*
Switzerland	Zimmerli 1998	*Scorpidium scorpoides*, *Drepanocladus revolvans*, *Carex rostrata* (*C. utriculata*), *Sphagnum subsecundum* Nees in Sturm

Parasites and disease

Only a limited amount of research has been conducted examining the effects of pathogens or parasites on *Carex* species, and none apparently involving *C. limosa* within Region 2. McIntire and Waterway (2002) examined the incidence of a smut on *C. limosa*, *C. rariflora*, and their hybrid in a Quebec peatland. They found that, although the smut infected both *C. limosa* and *C. rariflora* ramets, it occurred 5 to 20 times more commonly on hybrids than on either parental species (McIntire and Waterway 2002), and the overall incidence of the smut within the *C. limosa* occurrence was relatively low. Whether this organism or any other parasites or pathogens affect *C. limosa* in the region is unknown.

CONSERVATION

Threats

In general, an assessment of the conservation status of any species needs to take into account a variety of factors. The relative rarity of a species assessed at local, regional, and global scales is, of course, of primary interest. An additional factor of critical importance is an assessment of the relative stability of the ecosystems supporting known occurrences.

The degree to which a particular habitat characteristic (e.g., water table depth) responds to a disturbance can be characterized as an ecosystem's stability, while ecological resilience refers to the degree to which such a characteristic returns to its original state following a disturbance (Rejmankova et al. 1999). Both attributes need to be considered when attempting to predict the potential ecological response of an individual species to different disturbance agents, as the fate of any given species is typically intimately intertwined with that of its ecological setting, particularly in species confined to small, discrete ecosystems like fens.

However, both stability and resilience need to be evaluated in terms of a species' basic life attributes and successional status, as the implications of a particular disturbance agent on an early-seral, annual species will likely differ significantly from that of a late-seral, perennial one. Likewise, species capable of vegetative growth and reproduction may have different effect thresholds and recovery times to disturbance than species lacking the capability.

Much of the following discussion, which outlines some of the basic types of disturbances likely to impact fens, is general in nature. Where possible, we attempt to specifically predict disturbance effects on *Carex limosa* occurrences. However, the data necessary for confident prediction of the response of particular occurrences to specific disturbances is largely unavailable. Therefore, this assessment is based first on principles extrapolated from existing case studies. Also, we note where there is evidence of specific, impending threats to *C. limosa* occurrences; otherwise, discussions refer to potential threats.

Hydrologic alteration

Direct hydrologic alteration by ditching represents one of the most common and long-lasting anthropogenic impacts to fens in the region. For example, Cooper et al. (1998) found that ditches constructed through a fen in Rocky Mountain National Park were still effectively intercepting and diverting inflow nearly 75 years after they were abandoned. The resulting lower water tables facilitated invasion of the fen by *Deschampsia cespitosa* (L.) Beauv., a native grass common in seasonally dry, mineral soil sites (Cooper et al. 1998). Similar changes may promote invasions by non-native species as well (**Figure 14**).

The direct hydrologic alteration of fens generally reduces the habitat suitability for species such as *Carex limosa*, which generally occur in the wettest microsites. The fens supporting many known *C. limosa* occurrences occur on public lands managed by either the National Park Service or the USFS, and many are found in designated wilderness areas, which typically receive some degree of *de facto* protection due to their inaccessibility. Thus, the overall threat from future ditching or direct dewatering is presumably low for most extant *C. limosa* occurrences. However, where there are pre-existing water rights, these can take precedence over regulations or management directed at ecosystem or species conservation, as has been observed at sites supporting *C. limosa* on the Grand Mesa National Forest (Austin personal communication 2004). In addition, large numbers of fens in the region were historically ditched; these ditches or other engineering structures often continue to function though no longer maintained or used.

A variety of actions outside of the immediate boundaries of fens can alter their hydrology, sediment budgets, or water chemistry, and potentially affect dependent wetland species. The water balance of individual basins supporting peatlands varies as a function of the precipitation inputs, evaporation and transpiration losses, and the amount of water stored as

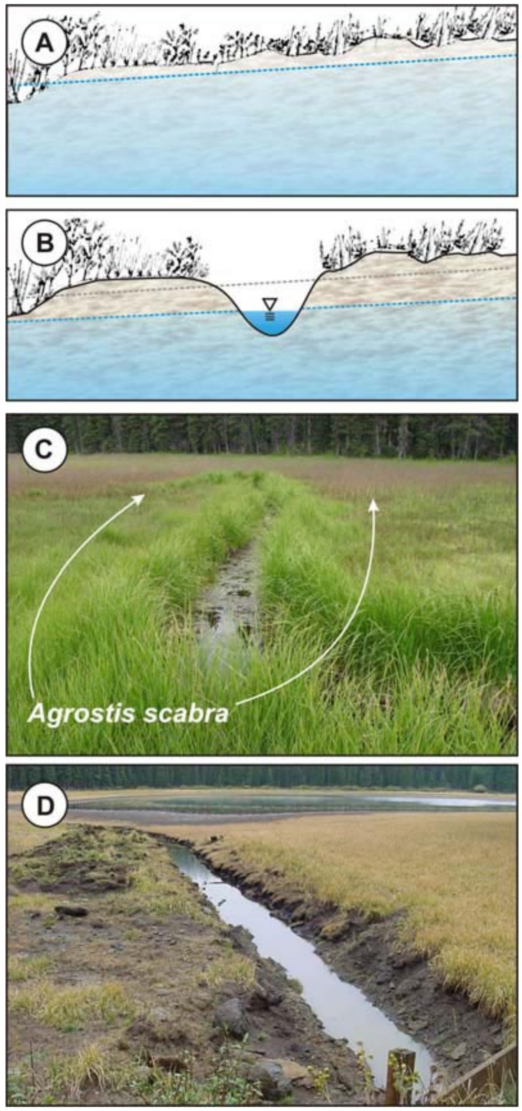

Figure 14. Schematic diagram illustrating water table in a hypothetical fen before (**A**) and after (**B**) ditching. The Grand Mesa National Forest, CO fen pictured in panel **C** has been ditched, lowering the water table and facilitating invasion by the non-native Agrostis scabra Willd., the reddish vegetation in the back of the photograph (Photograph by D. Cooper). Panel **D** is a photograph from another fen on the Grand Mesa National Forest, CO that has recently been ditched (Photograph by G. Austin, used with permission).

groundwater (Mitsch and Gosselink 2000). Vegetation in surrounding uplands influences this balance through effects on transpiration and interception of rain or snow, which is susceptible to subsequent loss through evaporation or sublimation (Kauffman et al. 1997). Thus, any process that significantly alters upland vegetation can impact nearby wetlands.

Timber harvest

Changes in basin vegetation cover due to timber harvest can alter surface runoff from basins through effects on evapotranspiration rates and snowpack accumulation patterns. For example, canopy removal in a subalpine watershed in Colorado increased precipitation reaching the forest floor by approximately 40 percent and increased peak snowpack water equivalent by more than 35 percent (Stottlemyer and Troendle 1999, Stottlemyer and Troendle 2001). Logging, whether clearcutting or partial thinning, typically results in increased annual and peak streamflow in logged watersheds (Troendle and King 1987). However, the effects of increased water yield and surface inflows to peatlands are difficult to predict, and both positive and negative effects are possible (**Figure 15**). As an example, increased water yield from upland portions of peatland watersheds could generate wetter conditions conducive to *Carex limosa* establishment and persistence. However, since fens in the Southern Rocky Mountains form only in physically stable locations where stream erosion and sediment deposition are limited, increased sediment yields resulting from upland vegetation removal could negatively impact peat formation and maintenance processes, adversely affecting *C. limosa* occurrences.

Since the majority of snowmelt passes through subalpine watersheds not as surface flow, but rather as subsurface flow where soil processes can significantly alter meltwater chemistry (Stottlemyer and Troendle 1999), changes in snowpack accumulation and melt rates due to changes in upland vegetation cover can affect water chemistry in a variety of ways. For example, Stottlemyer and Troendle (1999) observed significant increases in the average snowpack Ca^{2+}, NO_3^{-}, and NH_4^{+} content, and increased K^{+}, Ca^{2+}, SO_4^{2-}, NO^{3-}, and HCO^{3-} flux in shallow subsurface flows following logging treatments. The effect of these changes in surface and subsurface flows on peat chemistry and the potential effects on wetland flora are unknown. Because *Carex limosa* naturally occurs across a wide pH and nutrient gradient, such indirect effects of basin vegetation removal on the species are likely small.

Mineral sediment fluxes are typically low in peatlands. This is particularity true in fens in the central and southern Rocky Mountains (Cooper and Arp 2002). Although both mineral and organic inputs to fens could change following tree harvest, the short and long-term effects to fen vegetation are unknown. In addition to indirect effects, machinery used for harvesting can directly affect fens by creating ruts, compacting peat soils, and killing plants (Nugent et al. 2003).

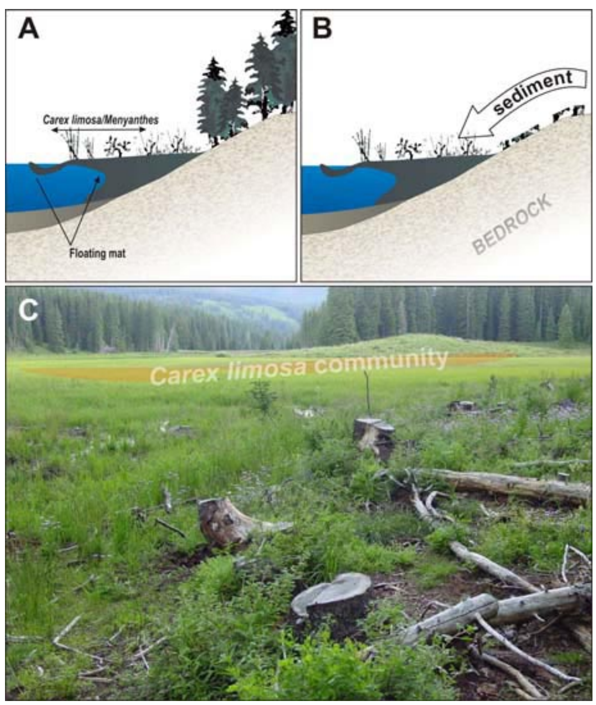

Figure 15. Schematic diagram (**A** and **B**) illustrating potential increases in sediment runoff from logging. Grand Mesa National Forest, CO fen supporting *Carex limosa* L., the margins of which have been logged. (Photograph by D. Cooper).

Fire

The indirect effects of fire occurring in adjacent uplands on fens supporting *Carex limosa* occurrences are likely similar to those of mechanical harvest, including increased water and sediment yield and changes in water chemistry. As with logging, the magnitude of these changes relative to pre-fire conditions would probably decrease over time, as the density and cover of upland vegetation increases (Troendle and King 1985).

In addition to the indirect effects of fire on fens, fire can directly impact *Carex limosa* individuals through plant mortality. Since fens typically remain saturated throughout the year, their ability to support fires is low relative to drier upland areas. In addition, fire return intervals characteristic of the subalpine forests surrounding Region 2 fens are relatively long compared to many boreal landscapes (Sherriff et al. 2001), suggesting that fire has a relatively minor role in the population dynamics of *C. limosa* within Region 2. However, during sustained droughts, well documented throughout the Holocene using a variety of climatic proxies (Cook et al. 1999), peat soils can dry sufficiently to allow fires to burn surface peat, potentially resetting successional processes and creating additional habitat for *C. limosa*.

We found no specific studies differentiating fire effects from prescribed or wildfire on fens from the region. However, since most Region 2 fens supporting occurrences of *Carex limosa* are found at relatively high elevations and in forest types with low natural fire recurrence intervals, they are unlikely to be targeted for prescribed burning.

Roads and trails

Roads and, to a lesser degree, trail networks can significantly affect local and watershed-scale hydrologic processes, and thereby affect fens supporting *Carex limosa*. Roads, trails, and their associated engineering structures such as culverts and ditches can alter natural drainage patterns, reduce interception and infiltration rates due to the removal of vegetation and soil compaction, and alter the hydrologic response of basins to both annual snowmelt runoff episodes and isolated convective storm events (Jones 2000, Forman and Sperling 2002). Increased overland flow typically results in a more rapid and extreme hydrologic response to precipitation events, potentially increasing erosion or sediment transport and deposition in affected systems.

Road and trail networks can have a variety of additional effects on wetlands, including the introduction of pollutants and the alteration of water chemistry (e.g., conductivity, cation concentrations, pH) due to road dust, increased sediment deposition, and chemicals used in road maintenance such as deicing agents (Wilcox 1986, Trombulak and Frissell 2000). Numerous variables can influence the effect of roads on wetlands such as road density, road slope and surface type, and the number, size, and design of engineering structures. Since these can vary so greatly within and among national forests, formulating general statements regarding the threat to *Carex limosa* due to roads or trails is difficult to make with confidence. However, there are certainly specific instances where the presence of roads has altered fen hydrology or sediment inflows. For example, Heidel and Laursen (2003a) suggest that a highway bordering the Clay Butte Fen on the Shoshone National Forest, which supports a particularly high quality *C. limosa* occurrence, may impede upslope groundwater flow into the basin.

An additional indirect effect on wetlands of roads and trails is the promotion of weed invasions. Road construction or maintenance activities can create disturbance conducive to the establishment of many exotics. Additionally, vehicles and the increased human traffic associated with them can provide an effective dispersal agent for weed propagules (Parendes and Jones 2000, Gelbard and Belnap 2003). A variety of exotic species invade wetlands, particularly those severely disturbed or hydrologically modified (Wilcox 1995). However, anecdotal evidence suggests that the extremely wet sites that typically support *Carex limosa* occurrences are unsuitable for the most common and pernicious invasives and that this indirect impact on the species is minor.

USFS travel management regulations prohibit off-highway vehicle (OHV) use in wetlands. However, instances of OHV trespass onto fens have been documented. Ruts caused by OHV access may function like small ditches, intercepting sheet flow on the surface of fens and altering fen hydrology. In addition, OHV use in or near wetlands may contribute pollutants from inefficient combustion and engine emissions (Havlick 2002). Though certainly a factor contributing to the degradation of some fens, we found no documented impacts to *Carex limosa*. However, such impacts could be important threats to local populations and ought to be considered by managers.

Peat extraction

Because of its high porosity and water holding capacity, peat has long been used as a lawn and garden soil amendment, as well as for industrial applications (WEC 2004). Because sites providing the necessary hydrologic conditions needed for peat accumulation are rare in the region and peat formation rates are low, most of the peat sold commercially in the United States is imported from Canada. No reliable statistics are available detailing peat production on USFS lands in Region 2, but anecdotal accounts suggest that it does occur in some locations. For example, relatively recent peat mining has removed nearly the entire peat body of some fens supporting *Carex limosa* communities on the Grand Mesa National Forest (Austin personal communication 2004).

Livestock and native ungulate grazing

The effects of livestock grazing on *Carex limosa* are largely unstudied. There are anecdotal accounts of grazing impacts to fens supporting *C. limosa*, but no quantitative data have been collected to evaluate the magnitude of the effects (Austin personal communication 2004). In general, livestock tend to avoid extremely wet sites, so their use of species like *C. limosa* may be relatively minor. However, livestock are known to opportunistically use fens, particularly when water levels are low such as during droughts (Proctor personal communication 2004). In addition to grazing effects, livestock can also affect fens through trailing and destroying peat through hoof action. However, we found no documented evidence of such impacts on sites supporting *C. limosa*.

Native ungulates can also significantly affect wetland flora, directly through herbivory and trampling, and indirectly through nutrient enrichment via urine or fecal deposits. In the San Juan National Forest, the authors have observed elk using fens that support *Carex limosa* but found no evidence of deleterious effects to the vegetation. Like livestock, elk typically avoid extremely wet locations, so they presumably represent a minor threat to *C. limosa* occurrences. Moose, however, are more likely to be found in wet sites, and consequently, they may locally impact *C. limosa* occurrences. Trampling from moose, for example, has been identified as a primary factor threatening a Grand County, Colorado fen supporting a floating mat community (Popovich personal communication 2004).

Recreational impacts

In general, sites supporting *Carex limosa* occurrences are unsuitable for roads or trails since they are saturated year-round. Except perhaps in winter, crossings must be bridged or stabilized, making such sites unappealing for transportation or recreation planners (Johnston 2001). In addition, work involving disturbance to such a wetland may require a Clean Water Act Section 404 permit.

Where existing trails or roads occur within a short distance of fens, they may facilitate human visitation and trampling effects resulting from hikers, campers, or recreational fishers. For example, visitation from hikers and campers has been identified as a potential threat to a fen supporting *Carex limosa* on the Routt National Forest in Colorado (Proctor personal communication 2004). Similar concerns have been raised for a fen on the Arapaho National Forest in Colorado (Popovich personal communication 2004).

There are no documented impacts from winter recreation such as cross-county skiing, snowshoeing, or snowmobiling on *Carex limosa* occurrences. However, snowmobile tracks have been observed in Colorado fens, raising concerns regarding their possible impacts on rare plant species such as *C. limosa* (Proctor personal communication 2004). For example, compaction of accumulated snow can potentially cause later spring melt and alter peat temperature profiles in fens, effectively reducing the length of the growing season for plants (Cooper and Arp 2002).

Exotic species

Although exotic species are widely recognized as one of the principle threats to native ecological systems (Mack et al. 2000, Crooks 2002), there is no evidence to suggest that *Carex limosa* is directly threatened by exotic species within Region 2. Although exotics such as Canada thistle (*Breea arvensis* Less.) may invade fens (Blumenthal and Jordan 2001), this is typically associated with severe hydrologic alterations such as ditching. In addition, lake-margin and floating mat environments supporting Region 2 *C. limosa* occurrences do not appear conducive to weed invasion.

Atmospheric deposition of pollutants

In general, fens may be vulnerable to the increased deposition of airborne nitrogen observed in portions of Region 2. While a wide variety of ecological responses have been shown to result from nitrogen deposition (Fenn et al. 2003), few studies have focused on fens specifically. Exceptions include Vitt et al. (2003) and Li and Vitt (1997), who examined the response of bryophytes (*Sphagnum fuscum* and *Tomenthypnum nitens*) to nitrogen deposition in bogs and fens in western Canada. They found that the response of individual species varied, but that in general, moss productivity increased and shrub productivity was unchanged (Li and Vitt 1997). There are no data from which to evaluate specific effects on *Carex limosa*, but any factor significantly altering productivity in fens could change vegetation composition and successional development.

Although most areas are exposed to some level of atmospheric nitrogen deposition, hotspots of elevated nitrogen deposition typically occur downwind of large metropolitan centers or significant agricultural operations (Fenn et al. 2003). Because *Carex limosa* exists across such a wide chemical gradient, it is unlikely that small shifts in nutrient availability will reduce the species' viability.

Climate change

Peatlands may be especially sensitive to major shifts in temperature or precipitation because of their strong dependence on watershed-scale hydrologic processes. The fidelity of *Carex limosa* to very wet sites suggests that the warmer regional temperatures predicted under some global climate change scenarios (U.S. Environmental Protection Agency 1998, Wagner 2003) may adversely affect the species. An increase in precipitation, called for by some models, may ameliorate the negative hydrologic effects of warmer temperatures, but still have a negative effect on the viability of *C. limosa* occurrences by shifting the balance between *C. limosa* and competing species (Moore 2002). For example, Moore (2002) found that production of graminoids and forbs increased in response to increasing water table elevations, as might occur under some climate change scenarios. This higher productivity could result in greater competition between *C. limosa* and associated vegetation.

Ultimately, the most important climatic factor influencing the future of peatlands in the region is likely to be the spatial and temporal patterns of precipitation (Moore 2002). Because of the dry climate of Region 2, areas capable of accumulating peat are rare on the landscape and rates of peat formation are exceedingly slow (Chimner et al. 2002, Chimner and Cooper 2003). Significant shifts in climate could reduce the viability of fens as a whole by altering their net carbon balance, changing wetlands from carbon gaining to losing systems (Chimner et al. 2002), and thereby threatening the persistence of *Carex limosa* occurrences.

Cumulative effects

As difficult as it is to demonstrate the effects of individual factors on a species, it is even more challenging to evaluate the cumulative effects of multiple stressors. However, cumulative effects need to be considered when discussing threats and evaluations of potential impacts from management activities (Reid 1993, Bedford 1999). Many individual ecological stressors act synergistically, meaning that mitigating for each individually may fail to achieve effective protection.

Conservation Status of Carex limosa in USFS Region 2

A full assessment of the conservation status of *Carex limosa* is best based on several factors, including the species' rarity, degree of habitat specialization, sensitivity to natural and anthropogenic stressors, and known population trends. Unfortunately, there are insufficient data from which to confidently evaluate population trends, so our assessment is largely based on our general knowledge of the species' life history, its habitats, and known threats to fens supporting the species in Region 2. Because *C. limosa* occurs exclusively in fens, which are limited in abundance and distribution, the current and future status of the species is intimately intertwined with its habitat.

Although rare, there is no quantifiable evidence to suggest that the distribution or abundance of *Carex limosa* is experiencing large changes in the region. The ability of *C. limosa* to persist vegetatively suggests that the species is not particularly vulnerable to moderate levels of environmental stochasticity. Periodic drought during the Holocene may have led to the local extirpation of *C. limosa* populations, contributing to the species' current rarity. However, the vulnerability of existing occurrences to future climate changes, particularly if they deviate from the historic range of variability, is unknown.

Extirpation of extant occurrences could also occur as a natural byproduct of successional changes associated with terrestrialization of basin fens. As ponds with floating mat fens gradually fill in with organic and mineral sediment, and as the floating mat becomes a solid peat body, the suitability of fens for *Carex limosa* may decrease, and the species may become displaced due to competition with other plants. However, because the process of peat accumulation is exceedingly slow in the region, it is not an imminent threat to existing occurrences.

Carex limosa shows strong fidelity for particular fen types. Although of limited abundance in Region 2, the depressional fens in which *C. limosa* occurs are largely confined to relatively high elevations and remote locations. In most instances, these sites appear secure from direct impacts. However, because of limited dispersal distances, no new occurrences are likely to form. Since no systematic survey of Region 2 fens has been conducted, it is certainly possible that additional occurrences could be found. Consequently, all fens should be carefully evaluated for the presence of *C. limosa* prior to significant shifts in management.

Management of Carex limosa in USFS Region 2

Implications and potential conservation elements

The relative rarity of *Carex limosa* in Region 2 is in part a function of its specialized habitat. The fens supporting the species are widely recognized by botanists and conservationists as important centers of biodiversity. Ensuring the viability of fens in general is the best approach to conserving *C. limosa*. Although we found no data suggesting that major changes in abundance are occurring in Region 2, data on the distribution and abundance of the species is incomplete, thus reducing our ability to confidently assess the status and population trends of the species.

As with many obligate wetland species, *Carex limosa* occurs along a relatively narrow range of hydrologic conditions. Any changes that alter the hydrologic functioning of wetlands that support the species may therefore pose a threat. Fen obligates such as *C. limosa* depend on the maintenance of stable water tables. Therefore, any management actions that significantly alter groundwater flow systems may threaten the sustainability of fens and their dependent flora.

Direct hydrologic alterations, such as ditching, have the greatest potential to negatively impact the species. Many fens in the region were ditched in the past and continue to exhibit impaired hydrologic function. These sites should be identified since the basic functioning of many systems can be relatively easily restored (Cooper et al. 1998). In addition to direct hydrologic impacts, many management practices can indirectly alter fen hydrologic regimes and thereby negatively affect the viability of occurrences. Since the hydrologic regime represents the single greatest influence on fen ecology, actions with the potential to alter water and sediment flux into fens (e.g., trail cutting, road building, timbering, prescribed fire, ski area development) should be critically evaluated early in project planning, and effects monitored following implementation.

Because peat accumulation rates in this region are exceedingly slow, the presence of significant peat bodies indicates relatively constant physical and hydrologic conditions over millennia. However, direct impacts within fens that degrade the integrity of the peat body, such as heavy trampling from livestock, can have significant impacts at fine scales. Although these impacts may not jeopardize the long-term functioning of the fen as a whole, given such slow rates of peat accumulation, severe impacts may take hundreds of years to recover naturally.

Tools and practices

Species and habitat inventory

Conducting habitat inventories in Region 2 fens would provide valuable information for the management of *Carex limosa* as well as other rare species such as *C. livida*, *C. leptalea*, *C. diandra*, *Drosera anglica*, and *D. rotundifolia*. Such inventories would result in improved information regarding the distribution of *C. limosa*, which would be important for prioritizing sites for further study and incorporation into management activities. To maximize their value, inventories ought to be based on standard, peer-reviewed protocols such as those developed by the National Park Service (1999). Less rigorous approaches such as photo-point monitoring can be employed at individual sites. Such an approach can provide general indications of changes in habitat condition but is of limited utility for forming confident assessments of trends.

Population and habitat monitoring

The development and implementation of quantitative population monitoring protocols would improve knowledge of the population dynamics of *Carex limosa*. Plot-based approaches are most desirable, as these most reliably facilitate evaluation of long-term trends in abundance. However, even qualitative approaches such as presence/absence surveys may be of value, providing an early indication of major changes. Population monitoring is most-profitably conducted in conjunction with habitat monitoring. For example, by monitoring water levels in fens, observed changes in the abundance of *C. limosa* can be more reliably tied to changes in hydrologic drivers. Because of the difficulty in identifying genetically unique individuals (i.e., genets), methods aimed at estimating the population of genets are less feasible than those tracking numbers of ramets.

Beneficial management actions

The principal way by which managers can promote the continued persistence of *Carex limosa* is maintenance of natural hydrologic regimes in wetlands supporting the species. Management activities likely to directly or indirectly affect fen hydrologic regimes should be avoided where possible. If such activities cannot be avoided, best management practices aimed at mitigating harmful effects ought to be pursued. At a broader scale, establishment of special protected areas (e.g., Research Natural Areas) would help to assure the conservation of *C. limosa*. Because maintenance of the hydrologic integrity of fens supporting the species is so important, an additional step that the USFS could take is to file for water rights on wetlands that support rare species, including *C. limosa*. Other actions such as the collection and storage of seed could be pursued.

Information Needs

Since wetlands supporting *Carex limosa* often support occurrences of other rare species and are functionally unique, future research needs to include broad-scale assessments of peatland distribution and abundance. Multiple techniques could be used, including the use of remotely sensed data (e.g., hyperspectral imagery, aerial photographs) to identify and map wetlands. The floating mats characteristic of the majority of Region 2 *C. limosa* occurrences likely exhibit distinct spectral signatures and could be readily flagged for field surveying. GIS analyses of existing data sets (e.g., National Wetlands Inventory data) in relation to the key climatic, hydrologic, and geological drivers of wetland formation, structure, and function could be undertaken. Such an approach has been successfully applied in the Bighorn National Forest, and is currently being developed for the San Juan, Gunnison, Uncompahgre, and Grand Mesa national forests (Winters et al. 2003).

In addition to broad-scale inventories of peatland abundance and distribution, more detailed studies relating basin morphometry, sediment and peat stratigraphy, and historical changes in community composition and vegetation structure determined through techniques such as radiocarbon dating are important for developing an understanding of peatland origin and development – essential information for predicating the long-term future of sites supporting *Carex limosa*.

Since few data regarding population size are available, comprehensive demographic surveys of known occurrences need to be conducted to better evaluate the current status of *Carex limosa* occurrences and to provide baseline data essential for effective monitoring. Known occurrences need to be periodically revisited and follow-up surveys conducted in order to identify potential trends in occurrences. A question of critical conservation significance for *C. limosa* is what are the relative turnover rates in ramets versus genets, and how do these differ among occurrences? Methods developed for answering this question could also be useful for monitoring other rare clonal species.

Additional information gaps include the role of seed banks in the population dynamics of the species and the relative importance, frequency, and prerequisite conditions necessary for sexual establishment. Such information is essential not only for understanding extant occurrences, but for developing approaches for restoring heavily degraded systems. If conducted in conjunction with studies of fen hydrology and vegetation patterns, these kinds of inquiries could significantly advance our understanding not just of *Carex limosa*, but of the systems the species inhabits.

The importance of collecting basic hydrologic and sediment data at individual wetlands cannot be overstated. These data can be extremely valuable in developing realistic models of fen vegetation dynamics, and for understanding and evaluating the effects of management activities on fens in general, and on *Carex limosa* specifically. Although such studies may appear prohibitively expensive or complicated at first glance, installation of even a few simple groundwater-monitoring wells, easily accomplished by a single individual in an afternoon, can yield invaluable data.

More information is needed about the physiochemical and hydrologic drivers of floating mat formation and development, and their sensitivity to anthropogenic disturbance. These environments provide critical habitat for several rare plant species in Region 2, including *Carex limosa*, *Drosera rotundifolia*, *D. anglica*, *C. livida*, *C. diandra*, and *Muhlenbergia glomerata*, yet they have rarely been studied in detail. Important topics relevant to conservation include rates of floating mat formation, characterization of mineral and organic sediment inputs into pristine systems versus those subject to varying degrees of disturbance, and evaluation of water and nutrient fluxes in floating mat sites and their response to various forest management activities.

More research needs to be done to improve our understanding of the history and underlying genetic structure characterizing Region 2 *Carex limosa* occurrences. Key questions include the genetic variability among clones in a given fen, among Region 2 fens, and among peatlands globally. Also of interest is the spatial structure of genetic variation among clones. Both questions could be addressed through methods such as allozyme polymorphism analysis (Hedren and Prentice 1996, Ford et al. 1998, Huh 2001), and would provide important insights useful for conservation or restoration.

There are few studies of fen restoration in the Rocky Mountains. However, the limited research that has been conducted suggests that restoration of fen vegetation is contingent upon effective restoration of wetland hydrology (Cooper et al. 1998). Typically this requires removing obstacles or diversions in the groundwater flow systems that support fens. Unfortunately, few studies have identified suitable plant propagation and establishment approaches for peatland species. Development of conservation strategies for *Carex limosa* in the region should therefore include research into effective restoration techniques.

Definitions

Achene – Small, dry fruit with a close-fitting wall surrounding a single seed (Hurd et al. 1998).

Bract – Reduced, modified leaf associated with flowers (Hurd et al 1998).

Hollow – A low area within a peatland that is wetter than surrounding hummocks (Crum 1988).

Hummock– A raised area within a peatland often formed around the roots of trees or shrubs that is generally drier and more acidic than nearby hollows (Crum 1988).

G/S1 – Critically imperiled globally/in state because of rarity (5 or fewer occurrences in the world/state; or 1,000 or fewer individuals), or because some factor of its biology makes it especially vulnerable to extinction (NatureServe 2004).

G/S2 – Imperiled globally/in state because of rarity (6 to 20 occurrences; 1,000 to 3,000 individuals), or because other factors demonstrably make it very vulnerable to extinction throughout its range (NatureServe 2004).

G/S3 – Vulnerable globally/in state or found locally globally/in state (21 to 100 occurrences; 3,000 to 10,000 individuals) (NatureServe 2004).

G/S4 – Apparently secure globally/in state, but it may be quite rare in parts of its range, especially at the periphery (usually more than 100 occurrences and 10,000 individuals) (NatureServe 2004).

G/S5 – Demonstrably secure globally/in state, but it may be quite rare in parts of its range (NatureServe 2004).

Lectotype – A specimen chosen as the standard bearer of a species, subspecies, or other taxonomic group (Wikipedia 2005).

Marl – An unconsolidated calcium carbonate deposit typically formed in freshwater lakes, but also deposited in very alkaline wetlands (Crum 1988).

Minerotrophic – Fed by groundwater that has been in contact with soil or bedrock and is therefore richer in nutrients than rainwater (Crum 1988).

Mycorrhiza – Symbiotic association between a fungus and the root of a higher plant (Wikipedia 2005).

Peat – An accumulation of undecomposed dead plant matter that forms when plant production exceeds decompositions, typically in areas where oxygen levels are low due to prolonged inundation (Crum 1988).

Peatland – A general term referring to wetlands with a peat substrate; includes fens and bogs (Crum 1988).

Poor fen – A weakly minerotrophic fen fed by waters that are weakly mineralized, generally with an acidic pH (about 3.5-5.0) (Crum 1988).

Propagule – Any dispersible unit capable of regenerating the species; can be individual seeds, fruits including seeds, spores, or in species capable of asexual reproduction, vegetative units such as cuttings (Wikipedia 2005).

Rich fen – A strongly minerotrophic fen fed by waters rich in minerals, generally with a circumneutral pH (Crum 1988).

Sensitive species – Species identified by the Regional Forester for which population viability is a concern as evidenced by significant current or predicted downward trends in population numbers or density and significant current or predicted downward trends in habitat capability that would reduce a species' existing distribution (USDA Forest Service 2004).

SNR – Species not assigned a NatureServe subnational rank (NatureServe 2004).

SX – NatureServe subnational rank denoting that the species is believed to be extirpated from state or province (NatureServe 2004).

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Appendix

USDA Forest Service Region 2 Carex limosa Herbarium and Natural Heritage Element Occurrence Records

The following table contains a list of USDA Forest Service Region 2 herbarium and Natural Heritage program element occurrence records for Carex limosa. The number listed in the Map key column corresponds to the location map presented in Figure 2 of the assessment. Record sources listed include the Wyoming Natural Diversity Database (WYNDD), Colorado Natural Heritage Program (CNHP), University of Colorado Herbarium (CU), Colorado State University Herbarium (CSU), Nebraska Natural Heritage Program (NNHP), Bessey Herbarium at the University of Nebraska (NEB), and the Rocky Mountain Herbarium (RM). Note that many occurrences are represented by more than one record.

Map key	Record source	State	County	Management	Record label description/comments
1	WYNDD	WY	Park	Shoshone National Forest	Beartooth Mountains, southeast end of Little Moose Lake, ca 0.5 air miles south-southeast of Ivy Lake outlet, ca 3.5 air miles northeast of Jim Smith Peak, ca 2.5 miles north of US Highway 212, Observed to be locally abundant within areas of suitable habitat. Plants mostly in fruit. Occurs with *Carex diandra*, *C. interior*, *Menyanthes trifoliata*, and *Eriophorum gracile*. Plants with mature perigynia. Floating mats at edge of *Salix planifolia* var. *monica/Carex aquatilis* community type. Soils histic and saturated.
1	WYNDD	WY	Park	Shoshone National Forest	Sabine Mellmann-Brown, Rocky Mountain Herbarium, Beartooth Range, wetland southeast of Little Bear Lake, 100 ca. south of US Highway 212, south of small rock outcrop. 80 percent fruiting, 20 percent vegetative. Occurs with *Carex scopulorum* and mosses, total vegetation cover about 30 percent. On floating mat, substrate exposed.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka: Cathedral Cliffs-Swamp Lake Wetland; ca 2.5 miles east of Crandall Ranger Station. Abundant in open, marly fen.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: Clarks Fork Valley: Swamp Lake, on north side of dirt road to K Bar Z Ranch; ca 34 air miles northwest of Cody. Marl deposits and hummocky, saturated ground at edge of open water; site dominated by *Triglochin maritimum* and *Eriophorum*.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: Swamp Lake wetlands below Cathedral Cliffs, ca 35 air miles northwest of Cody. In marl and water.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: Swamp Lake and Corral Creek on K Bar Z Guest Ranch near Crandall Ranger Station. Also S15. Calcareous bog with adjacent stand of *Picea glauca*; open bog.

Appendix table (cont.)

Map key	Record source	State	County	Management	Record label description/comments
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: at base of Cathedral Cliffs, just south of Cody-Crandall Road (Wyo Hwy 296), ca 1.5 miles east of Crandall Ranger Station. Also S14. Open, calcareous (marly) bog.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: at base of Cathedral Cliffs, just south of Cody-Crandall Road (Wyo Hwy 296), ca 1.5 miles east of Crandall Ranger Station. Also S14. Open, calcareous (marly) bog.
1	RM	WY	Park	Shoshone National Forest	S11-14 line. Bog.
1	RM	WY	Park	Shoshone National Forest	Swamp Lake. S11-14 line. Calcareous bog with *Carex* spp. and *Scirpus*.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: Clarks Fork Valley: Swamp Lake; ca 34 air miles northwest of Cody. SE1/4 S11. Quaking marl mats on open water; with *Carex simulata*, *Triglochin maritimum*, *C. livida*, and *Primula egaliksensis*.
1	RM	WY	Park	Shoshone National Forest	Northern Absaroka Mountains: Clarks Fork Valley: Swamp Lake; ca 34 air miles northwest of Cody. SE1/4 of SE1/4 S10. North shore of lake in quaking sphagnum bog dominated by *Carex simulata* and *Kobresia*.
1	RM	WY	Park	Shoshone National Forest	Beartooth Plateau: swamp on south side of US Hwy 212 across from junction with road to the Clay Butte Visitor Center. SE1/4 of NW1/4 S12. Open swamp with floating mats of *Carex limosa* and *C. simulata* surrounded by open water with *Nuphar* and *C. aquatilis*.
1	RM	WY	Park	Shoshone National Forest	Beartooth Range: wetland on south side of US Hwy 212 across from road to Clay Butte Lookout, ca 4.7 air miles south of Montana; ca 4 miles east of junction of US Hwy 212 and Wyo. Wet, quaking mats at edge of open water; soil orangish organic clay muck; community of *Carex limosa* and *C. rostrata* with patches of *C. buxbaumii* on drier sites.
1	RM	WY	Park	Shoshone National Forest	Absaroka Mountains: 0.25 miles north of Wyo Hwy 212, 40.9 air miles west of Cody. NE1/4 SW1/4 S10. Hillside forest community of *Pinus contorta* on granitic substrate; with *Shepherdia canadensis* and *Vaccinium scoparium*.
1	RM	WY	Park	Shoshone National Forest, Absaroka-Beartooth Wilderness	Beartooth Plateau: ca 3/4 air miles west of Lily Lake. NE1/4 SE1/4 S1. On south and west shores of pond, on small mossy hummocks with *Salix* can*dida*, *Carex utriculata*, and *C. aquatilis*.
1	RM	WY	Park	Shoshone National Forest, Swamp Lake Special Botanical Area	Beartooth Plateau: Little Moose Lake, ca 0.5 air miles south-southwest of Ivy Lake outlet. NE1/4 SW1/4 S26. In scattered patches on floating mat with *Carex aquatilis* *C. utriculata*, *Potentilla palustris*, and *Drosera anglica*.

Appendix table (cont.)

Map key	Record source	State	County	Management	Record label description/comments
1	WYNDD	WY	Park	Shoshone National Forest, Swamp Lake Special Botanical Area	Northern Absaroka Mountains, Clarks Fork Valley, Swamp Lake wetland on the north side of the Cathedral Cliffs and south of WY Highway 296, ca 34 air miles northwest of Cody. Observed in flower and fruit by W. Fertig during Wyoming Native Plant Society Field Trip. 08-21-1992: In flower and fruit. 19 colonies located in survey. Occurs with *Carex buxbaumii* and *C. simulate*. Most commonly found on hummocks in *Triglochin* - *Eleocharis* marl or on floating mats dominated by *C. simulata*. Rare at edge of *Picea glauca* muskeg community.
1	WYNDD	WY	Park	Shoshone National Forest	Fertig, W., Beartooth Range, wetland on south side of US Highway 212 across from junction with road to Clay Butte lookout, ca 4.7 air miles south of the Montana state line and ca 5 miles east of the junction of US Highway 212 and WY Highway 296. 08-01-1999: Several thousand plants observed in wetter parts of swamp by Fertig, Welp, and Mellmann-Brown. Plants in flower and fruit. Occurs with *Carex buxmaumii*, *C. diandra* and *Menyanthes trifoliata*. 08-26-1993: Observed in flower and fruit by Fertig,, Wet, quaking mats at edge of open water on orangish, organic-rich clay muck. In community dominated by *Carex simulata* and *C. limosa* or *C. rostrata* [*C. utriculcata*].
1	WYNDD	WY	Park	Shoshone National Forest	Beartooth Range, ca 1 air mile north of highways 212 and 296 junction, ca 0.75 air miles west of Lily Lake [at pond indicated on 7.5' topographic map]. 08-07-1995: Infrequent on south and west shores of pond. Associated with *Carex rostrata* and *C. aquatilis*. On *Salix c*and*ida* hummocks in *S. c*and*ida/Carex* spp. vegetation type. Soil wet, parent material granitic. Slope less than 5 percent, aspect north to east.
1	WYNDD	WY	Park	Shoshone National Forest	Beartooth Range, pair of unnamed ponds ca 0.7 miles northeast of Lily Lake, ca 0.2 miles west of Lake Creek, ca 1.8 miles north of US Highway 212. 1996-08-31: In flower and fruit. Several thousands of stems found throughout wetland (often locally dominant on floating mats). Occurs with *Calamagrostis canadensis*, *Drosera anglica*, *Eriophorum gracile*, *Carex lasiocarpa*, *C. buxmaumii*, *C. diandra*, and *C. rostrata*, occurs in two main vegetation types: (1) floating mats of *Sphagnum* on rich organic muck at edge of ponds; (2) *C. aquatilis/ C. buxmaumii* sedge meadows on low, moist banks of ponds.
2	WYNDD	WY	Big Horn	Bighorn National Forest	Big Horn Range, Meadowlark Lake near inlet [south of US Highway 16, probably near the Lake Point picnic area]. 08-18-1951: in fruit. Sedge bog.

Appendix table (cont.)

Map key	Record source	State	County	Management	Record label description/comments
2	RM	WY	Big Horn	Bighorn National Forest	Big Horn Range: Meadowlark Lake. N1/2 S33. Sedge bog near inlet.
3	RM	WY	Sublette	Bridger National Forest, Bridger Wilderness	West Slope Wind River Range: Southern and western shores of North Fork Lake, ca 7 air miles northeast of east shore of Boulder Lake, ca 18 air miles east-northeast of Pinedale. Also S16. Marshy meadow in shallow basin bordering small pond to west of lake.
4	WYNDD	WY	Albany	Medicine Bow National Forest	Medicine Bow Mountains, from Hwy 130 ca. 12 miles north on Sand Lake Road and ca. 0.8 miles east on FS Rd 101E; ca. 12 air miles north of Centennial. 07-19-2003: Small lake complex with peatland, on glaciated terrain. Local dominant in floating and non-floating peat on or near the two largest open water bodies, surveyed by B. Heidel, with G. Jones, J. Proctor, and K. Carsey. Occurs with *Menyanthes trifoliata* on floating peat, and with *Eleocharis quinqueflora*.
5	RM	WY	Carbon	Medicine Bow National Forest, Huston Park Wilderness	Sierra Madre/Park Range: Sierra Madre: ca 1 air mile south of Red Mountain. Also S6 and T13N R86W S1., Bog and lake habitat; semi-aquatic.
5	RM	WY	Carbon	Medicine Bow National Forest, Huston Park Wilderness	Sierra Madre Mountains: Medicine Bow National Forest: ca 0.5 miles west-southwest of northwest end of Long Park. NW1/4 S6. Edge of sedge bog.
5	WYNDD	WY	Carbon	Medicine Bow National Forest	Sierra Madre, two headwater locations on opposite sides of the Continental Divide: (1) Secs 05-06: sedge bog ca 0.5 miles west-southwest of northwest end of Long Park [ca 2 miles south of Battle] at head of North Fork of Encampment Creek. (2) Sec 1: ca 1 a, 2003-09-02: Co-dominant in Sec. 6 with *Menyanthes trifoliata* in a discontinuous zone mainly on the western edge of open water, as well as southern lake margin. Observed by B. Heidel. 2003-08-31: Dominant in Sec. 1 in a narrow zone around small area of op, Floating peatland mat adjoining open water habitat with *Nuphar polysepala*, in a lake and a separate pool.
6	CNHP	CO	Jackson	Routt National Forest	Neely, B. and Richter, H. 1991. Field survey to Big Creek Lakes of Aug. 21, 1991.
6	CNHP	CO	Jackson	Routt National Forest	Neely, B. and A. Carpenter. 1989. Field survey to Jackson County of Aug. 1-15.
6	CU	CO	Jackson	Routt National Forest, Mount Zirkel Wilderness	Jackson County, Colorado, USA. Park Range, Routt National Forest; large kettle lake just north of Shafer Creek and north of Fryingpan Trail. TRS: T10N R82W SEC10, *Sphagnum* mat.
6	CU	CO	Jackson	Routt National Forest, Mount Zirkel Wilderness	Jackson County, Colorado, USA. Park Range, Routt National Forest; kettle lake between Shafer and Goose creeks, 0.25 mile north of Frying Pan Trail. TRS: T10N R82W SEC10, *Sphagnum* mat.

Appendix table (cont.)

Map key	Record source	State	County	Management	Record label description/comments
6	CU	CO	Jackson	Routt National Forest, Mount Zirkel Wilderness	Jackson County, Colorado, USA. Park Range, Routt National Forest; kettle lake between Shafer and Goose creeks, 0.25 mile north of Frying Pan Trail. TRS: T10N R82W SEC10, *Sphagnum* mat.
6	CNHP	CO	Jackson	Routt National Forest	Lily Lake, UTM 13 413980E 4478537N (WGS84/ NAD83), USGS Jack Creek Ranch Quad, Elevation 9,656.9 ft. / 2,943.3 m (USGS NED), 2005 CONPS survey
6	CNHP	CO	Jackson	Routt National Forest	Sawmill Lake, UTM 13 362981E 4488209N (WGS84/ NAD83), USGS Teal Lake Quad, Elevation 8,910.2 ft. / 2,715.7 m (USGS NED), 2005 CONPS survey
6	CNHP	CO	Jackson	Routt National Forest	Big Creek Lakes, UTM 13 364286E 4531061N (WGS84/ NAD83), USGS Pearl Quad, Elevation 9,005.9 ft. / 2,744.9 m (USGS NED), 2005 CONPS survey
7	CNHP	CO	Larimer	Roosevelt National Forest	Reid, Marion and Nan Lederer. 1994. Field survey for CNHP.
7	CNHP	CO	Larimer	Roosevelt National Forest	Spackman, S., J. Sanderson, S. Kettler, and K. Fayette. 1996. Larimer County Filed Survey for Colorado Natural Heritage Program.
7	CSU	CO	Larimer	Roosevelt National Forest	County Rd 103, 1.5 miles south of junction of Laramie River and Two & One Half Mile Creek, moist peat.
7	CU	CO	Larimer	Roosevelt National Forest	Larimer County, Colorado, USA. 1.2 miles north of Chambers Lake, on east side of Co. Rd. 103. TRS: T8N R75W SW¼ of SEC30, On very wet peat; adjacent to a small area of open water; uncommon.
7	CU	CO	Larimer	Roosevelt National Forest, Comanche Peak Wilderness	Larimer County, Colorado, USA. Roosevelt National Forest, Comanche Peak Wilderness, 1.5 miles northeast of Big South Trailhead. Un-named ponds in wide level basin. TRS: T, Wet peaty margin of ponds in wide level basin, with *Carex lasiocarpa*, *Menyanthes trifoliata*, *Pedicularis groenl*and*ica*, and *Galium trifidum*.
8	CNHP	CO	Grand	Rocky Mountain National Park	Yeatts, L. 1988. specimen at the Rocky Mountain National Park Herbarium (Collection # 1975).
8	CU	CO	Grand	Rocky Mountain National Park	Grand County, Colorado, USA. Rocky Mountain National Park, Big Meadows, approximately .25 mile east, pond just south of Green Mountain trail. UTM: 430880E 4462010N, Kettle lake surrounded by *Carex* fen & *Pinus contorta* forest; with *C. magellanica*, *Menyanthes trifoliata*, and *Nuphar luteum*; floating mat at edge of pond; flat slope; open exp.
8	CU	CO	Grand	Rocky Mountain National Park	Grand County, Colorado, USA. Rocky Mountain National Park, Green Mt. Trail to Big Meadows, “Green Mt. Trail Pond”. Forming floating mats on pond.

Appendix table (cont.)

Map key	Record source	State	County	Management	Record label description/comments
8	CU	CO	Grand	Rocky Mountain National Park	Grand County, Colorado, USA. Rocky Mountain National Park, Long Meadows wetlands draining into Timber Creek to the north & Onahu Creek to the south; In pond near north end of Long Meadows. U, In pond, bordered on north side by *Carex aquatilis* fen; forming quaking mats with co-dominant *C. canescens* in shoreline muck and extending into water; with *Menyanthes trifoliata*.
9	CU	CO	Grand	Routt National Forest	Jackson County, Colorado, USA. Park Range, Routt National Forest; large un-named kettle lake southeast of Big Creek Lakes just west of Pleasant Valley ditch TRS: T1N R82W SEC27, Floating mat in center of lake.
9	CU	CO	Grand	Routt National Forest	Jackson County, Colorado, USA. Park Range, Routt National Forest; kettle lakes southeast of Big Creek Lakes 0.3 mi W of Forest Road 660, 1 mile north of North Fork North Platte River. TRS: T1, Kettle lakes.
10	CNHP	CO	Gunnison	Gunnison National Forest	Sanderson, J. 1994. Field survey. Plot # 94JS41.
11	CU	CO	Park	Pike National Forest, Lost Creek Wilderness	Park County, Colorado, USA. East Lost Park, ca. 1.5 miles downstream from Lost Park Campground, Pike National Forest. TRS: T9S R72W SEC18, In rich fens dominated by *Eriophorum gracile*, with *Carex livida* and *C. tenuiflora*.
11	CSU	CO	Park	Pike National Forest, Lost Creek Wilderness	East Lost Park ca 1.5 miles downstream from Lost Park Campground, rich fens.
11	CU	CO	Park	Pike National Forest, Mount Evans Wilderness	Park County, Colorado, USA. Mud Lakes, in Pike National Forest. TRS: T6S R73W SEC1, In wet fen with *Carex aquatilis*, *Eriophorum angustifolium*, and *C. saxatilis*.
11	CU	CO	Park	Pike National Forest, Mount Evans Wilderness	Clear Creek County, Colorado, USA. Arapaho National Forest, Mt. Evans Wilderness, Mud Lakes. TRS: T6S R73W SEC1, In wet fen on level saddle, with *Carex saxatilis* and *C. aquatilis*.
11	CU	CO	Clear Creek	Pike National Forest, Mount Evans Wilderness	Clear Creek County, Colorado, USA. Guanella Pass, Pike National Forest; small fen ¼ mile east of Pass. TRS: T5S R74W, Small fen, with wet peaty soil but not standing water; with *Eriophorum gracile* and *Carex saxatilis*.
12	CSU	CO	Gunnison	Gunnison National Forest	Peeler Basin ca 5 miles northwest of Crested Butte, small pool edge, some floating in water.
12	CU	CO	Gunnison	Gunnison National Forest, Raggeds Wilderness	Gunnison County, Colorado, USA. Small pool, Peeler Basin, Subalpine zone; small pool (this collection from a mat so far from the shore as to be floating and aquatic).
12	CU	CO	Gunnison	Gunnison National Forest, Raggeds Wilderness	Gunnison County, Colorado, USA. Small pool, Peeler Basin., Subalpine zone; small pool (this collection from a mat so far from the shore as to be floating and aquatic).
12	CSU	CO	Gunnison	Gunnison National Forest, Raggeds Wilderness	Peeler Basin ca 7 miles northwest of Crested Butte, small pool edge.

Appendix table (concluded).

Map key	Record source	State	County	Management	Record label description/comments
13	CU	CO	San Juan	San Juan National Forest	San Juan County, Colorado, USA. 0.25 mile southeast of Molas Pass, 15 miles southwest of Silverton. TRS: T40N R9W SEC19,
13	CU	CO	San Juan	San Juan National Forest	San Juan County, Colorado, USA. Weminuche Wilderness, West Needle Mts., Crater L. UTM: 13 026055E 4173060N, Large revegetating morainal kettle pond in *Picea engelmannii* forest opening just west of Crater Lake; in muck zone bounding shallow water; with *Carex canescens* and *Eleocharis quinquiflora*
13	CU	CO	San Miguel	San Juan National Forest	San Miguel County, Colorado, USA. Prospect Basin, 10 km south of Telluride, In *Menyanthes* fen.
14	CNHP	CO	Conejos	Rio Grande National Forest	Harrington, H. 1945. Specimen at Colorado State University herbarium.
14	CSU	CO	Conejos	Rio Grande National Forest	Near Flower Lake, west of Platoro.
14	CSU	CO	Conejos	South San Juan Wilderness	Near Green lake, swamp.
15	NEB	NE	Cherry	Private	T30 N R32W, NW1/4 SW1/4 S35, One colony seen on sedge peat mats 40 to 50 ft. west of sand mound in fen south of Boardman Creek, 4 miles south, 10 miles west of Merritt Reservoir; with *Carex prairea*, *C. interior*, *Caltha palustris*, *Salix petiolaris*, and *Menyanthes trifoliata*, June 19, 1996.
15	NEB	NE	Cherry	Private	Locally common on mucky sedge peat mats in fen near fence south of Goose Creek, west side of US 83, ca. 29 miles north of Thedford; with *Carex prairea*, *Triglochin*, *Menyanthes*, and *Eriophorum gracile*; culms gray-green. June 21, 1996.
15	NEB	NE	Cherry	Private	T28N R37 W S1/2 S14. Rare on peat mounds at Silver Lake fen.
15	NNHP	NE	Cherry	Private	USGS Windmill Lake Quad, Elevation 3,060.0 ft. / 932.7 m.
15	NNHP	NE	Cherry	Private	UTM 14 331707E 4710848N, USGS Chesterfield Flats Quad, Elevation 3,081.1 ft. / 939.1 m